DOCUMENT RESUME

ED 185 315 CE 024 757

TITLE	Opticalman 3 & 2, Naval Education and Training Command Rate Training Manual and Nonresident Career Course. Revised, 1979.
INSTITUTION	Naval Education and Training Program Development Center, Pensacola, Fla.
REPORT NO	NAVEDTRA-10205-B
PUB DATE	79
NOTE	510p.; Small type in diagrams will not reproduce well.
EDRS PRICE	MF02/PC21 Plus Postage.
DESCRIPTORS	*Curriculum; *Equipment Maintenance; Independent Study; Learning Activities; Light; *Military Training; Navigation; *Optics; *Repair; Spectroscopy
IDENTIFIERS	*Navy; Opticalmen

ABSTRACT

This document contains a U.S. Navy Rate Training Manual and Nonresident Career Course which form a self-study package to teach the theoretical knowledge and mental skills needed by the Opticalman Third Class and Opticalman Second Class. (Opticalmen maintain, repair, and overhaul telescopic alidades, azimuth and bearing circles, binoculars, compasses, gunsights, sextants, hand-held rangefinders, night vision equipment, submarine periscopes and other precision instruments.) Information in the Rate Training Manual (RTM) is divided into the following twelve chapters: (1) Advancement; (2) The Nature of Light; (3) Mirrors and Prisms; (4) Lenses; (5) Basic Optical Systems; (6) Design and Construction; (7) Maintenance Procedures--Part I; (8) Maintenance Procedures--Part II; (9) Machine Tool Operations; (10) Optical and Navigation Equipment; (11) Night Visual Sights and Gunsights; and (12) Submarine Periscopes. A U.S. Customary and Metric System Units of Measurement table is appended. The Nonresident Career Course (NRCC) follows the RTM index of key terms. The NRCC contains a set of assignments keyed to reading assignments in the Rate Training Manual. It is recommended that this training package be combined with on-the-job training for greater effectiveness. (BM)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED185315

OPTICALMAN 3 & 2

CE 024 757

NAVAL EDUCATION AND TRAINING COMMAND

RATE TRAINING MANUAL AND NONRESIDENT CAREER COURSE

NAVEDTRA 10205-B

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

The words "he," "his," and "him" may appear occasionally in this publication for economy in communication. Their usage is not intended to indicate gender nor to affront nor to discriminate against anyone studying *Opticalman 3 & 2*, NAVEDTRA 10205-B.

PREFACE

This Rate Training Manual and Nonresident Career Course (RTM/NRCC) form a self-study package to teach the theoretical knowledge and mental skills needed by the Opticalman Third Class and Opticalman Second Class. To most effectively train Opticalmen, this package may be combined with on-the-job training to provide the necessary elements of practical experience and observation of techniques demonstrated by more senior Opticalmen.

Completion of the NRCC provides the usual way of satisfying the requirements for completing the RTM. The set of assignments in the NRCC includes learning objectives and supporting questions designed to help the student learn the material in the RTM.

This RTM was revised by PICM K. B. Ferguson, and final preparation of the text and NRCC for printing was done by OMC L. T. Stagg of the Naval Education and Training Program Development Center, Pensacola, Florida, for the Chief of Naval Education and Training.

Revised 1979

Stock Ordering No.
0502-LP-051-0260

Published by
NAVAL EDUCATION AND TRAINING PROGRAM
DEVELOPMENT CENTER

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.: 1979

4

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CONTENTS

CHAPTER Page

1. Advancement 1-1
2. The Nature of Light 2-1
3. Mirrors and Prisms 3-1
4. Lenses 4-1
5. Basic Optical Systems 5-1
6. Design and Construction 6-1
7. Maintenance Procedures–Part I 7-1
8. Maintenance Procedures–Part II 8-1
9. Machine Tool Operations 9-1
10. Optical and Navigation Equipment 10-1
11. Night Visual Sights and Gunsights 11-1
12. Submarine Periscopes 12-1

APPENDIX

I. U.S. Customary and Metric System Units of Measurement AI-1

INDEX I-1

Nonresident Career Course follows Index

CREDITS

The illustrations indicated below are included in this edition of *Opticalman 3 & 2* through the courtesy of the designated companies, publishers, and associations. Permission to use these illustrations is gratefully acknowledged. Permission to reproduce these illustrations and other materials in this publication should be obtained from the source.

Source	Figures
South Bend Lathe Works	9-11, 9-12, 9-13, 9-15, 9-16, 9-18, 9-19, 9-20, 9-21, 9-22, 9-23, 9-24, 9-25, 9-26, 9-32, 9-35, 9-36, 9-38, 9-39, 9-40, 9-41, 9-42, 9-46, 9-47, 9-48, 9-49, 9-50, 9-52, 9-53, 9-54, 9-57, 9-58, 9-60, 9-61, 9-63, 9-65, 9-66
Reed-Prentice Corporation	9-14
Brown & Sharp Manufacturing Company	9-54, 9-57, 9-58, 9-60, 9-61, 9-63, 9-66, 9-65
Cincinnati Milling Machine Co.	9-56
Cleveland Twist Drill Co.	9-5, 9-6

CHAPTER 1

ADVANCEMENT

This training manual is designed to help you increase your knowledge in the various aspects of the Opticalman rating and to help you advance in rating to OM3 and OM2. Your contribution to the Navy depends on your willingness and ability to accept increasing responsibilities as you advance in rate. When you assume the duties of an Opticalman, you begin to accept certain responsibilities for the work of others. As you advance in your career, you accept responsibilities in military matters as well as in the occupational requirements of the Opticalman rating.

OPTICALMAN RATING

Opticalmen maintain, repair and overhaul telescopic alidades, azimuth and bearing circles, binoculars, compasses, gunsights, sextants, hand-held rangefinders, night vision equipment, submarine periscopes and other precision instruments. This includes inspection, casualty analysis, disassembly, repair, replacement or manufacture of parts, cleaning, reassembly, collimation, sealing, drying, gassing, and refinishing of surfaces.

The Opticalman rating is a general rating. The work of an Opticalman requires a high degree of intelligence and mechanical aptitude. Optical instruments are technical in nature, expensive, and delicate. For these reasons, just anyone cannot perform satisfactorily the work of an Opticalman. Intelligence is required to understand the principles of operation, and mechanical aptitude is necessary to repair and adjust the instruments.

Opticalmen generally are assigned duty in optical shops aboard repair ships or tenders and in stateside or overseas ship repair facilities. Occasionally, however, they are assigned duty ashore as instructors in Opticalman schools. Some Opticalmen are assigned to recruiting duty; others are assigned to Naval Reserve training units.

At the third or second class level, Opticalmen generally do not have the responsibility for administering an optical shop; but an Opticalman 2 is responsible for preparing casualty analysis inspection sheets for instruments and also for the maintenance of records and logs in the shop. Opticalmen on duty at the 3 or 2 level should therefore observe the work of Opticalmen at the first class and chief levels and learn as much from them as possible about the work of a shop supervisor. This is the only way to develop to the maximum your usefulness to the Navy as an Opticalman. Be prepared for greater responsibility when it is assigned to you.

Shop safety is something you should always emphasize. When using tools and operating machines, it is easy to injure yourself. This not only causes personal discomfort but results in a monetary loss to the Navy during your absence from work. Opticalmen should keep the shop in excellent working shape and hazard-free and work individually and collectively in a manner which minimizes personal injury.

This manual is organized to give you a systematic understanding of your job. The occupational standards used in preparing the text are contained in the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* NAVPERS 18068-D. We recommend that you study the Opticalman section of NAVPERS 18068-D to gain an understanding of the skills required of an Opticalman. Then, study the subject matter carefully. The knowledge you gain will enable you to become a more proficient repairman and the Navy will profit from your skills.

NAVY ENLISTED CLASSIFICATION CODES

The Opticalman rating is a source of two Navy Enlisted Classification Codes (NEC's). NEC's reflect special knowledge and skill in certain ratings. The NEC coding system is a form of management control over enlisted skills. It identifies skills and training required for specific types of operations or equipment. The Chief of Naval Personnel details personnel who have acquired those skills to fill billets that require the skills. The NEC's that Opticalmen may earn at certain grade levels are granted upon satisfactory completion of an applicable course of instruction at a Navy school. Your personnel office will have complete information on NEC's and qualification procedures.

THE NAVY ENLISTED ADVANCEMENT SYSTEM

Some of the things you gain through advancement are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

But the advantages of advancing in rate are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By each advancement, you increase your value to the Navy in two ways. First, you become more valuable as a specialist in your own rating. And second, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy.

The basic ideas behind the advancement system have remained stable for many years, but specific portions may change rather rapidly. It is important that you know the system and follow changes carefully. BUPERS Notice 1418 will normally keep you up-to-date.

The normal system of advancement may be easier to understand if it is broken into two parts.

1. Those requirements that must be met before you may be considered for advancement.
2. Those factors that actually determine whether you will be advanced.

QUALIFYING FOR ADVANCEMENT

In general, to qualify (be considered) for advancement, you must:

1. Have a certain amount of time in paygrade.
2. Demonstrate knowledge of material in your mandatory Rate Training Manuals by achieving a suitable score on your command's test, by successfully completing the appropriate NRCC's or, in some cases, by successfully completing an appropriate Navy school.
3. Demonstrate ability to perform the Personnel Advancement Requirements (PAR), NAVPERS 1414/4.
4. Be recommended by your commanding officer.
5. For petty officer third class and second class candidates ONLY, demonstrate knowledge of military subjects by passing a locally administered military/leadership examination based on the naval standards for advancement (from NAVPERS 18068 series).
6. Demonstrate knowledge of the technical aspects of your rate by passing a Navywide advancement examination based on the occupational standards applicable to your rate (from NAVPERS 18068 series, those standards listed at and below your rate level).

Figure 1-1 is a detailed view of the requirements for advancement of active duty personnel and figure 1-2 is similar information for inactive duty personnel. Remember that the occupational standards can change. Check with your division officer or training officer to be sure that you know the most recent standards.

If you meet all of the above requirements satisfactorily, you become a member of the group from which advancements will be made.

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	†E6 to E7	†E7 to E8	†E8 to E9
TIME IN GRADE	6 mos.	6 mos.	9 mos.	12 mos.	36 mos.	36 mos.	36 mos.	36 mos.
SCHOOL	Recruit Training. (C.O. may advance up to 10% of graduating class.)		Class A for PR3, DT3, IS3, AME3, HM3, FTB3, MT3, MU3, EW3, CT3	Naval Justice School LN2		Navy School for AGC, MUC	Assistant Bandleader Course MUCS	Assistant Bandleader Course MUCM
PERSONNEL ADVANCEMENT REQUIREMENT (PAR) NAVPERS 1414/4			Personnel Advancement Requirement (PAR) must be completed for advancement to E-4 through E-7.					
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS**	Locally prepared tests.	See below.	Navywide examinations required for all PO advancements. Military leadership exam required for E-4 and E-5.			Plus selection board for E-7, E-8, and E-9.		
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NAVEDTRA 10052 (current edition).					Nonresident career courses and recommended reading. See NAVEDTRA 10052 (current edition).	
AUTHORIZATION	Commanding Officer		NAVEDTRAPRODEVCEN					

*All advancements require commanding officer's recommendation.
†2 years obligated service required for E-7, E-8, and E-9.
**For E-2 to E-3, NAVEDTRAPRODEVCEN exams or locally prepared tests may be used.

Figure 1-1.—Active duty advancement requirements.

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E7 to E8	E8 to E9
TOTAL TIME IN GRADE	6 mos.	6 mos.	9 mos.	12 mos.	36 mos.	36 mos.	36 mos.	36 mos.
TOTAL TRAINING DUTY IN GRADE†	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS			Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit in accordance with BUPERSINST 5400.42 series.							
PERSONNEL ADVANCEMENT REQUIREMENT (PAR) NAVPERS 1414/4			Personnel Advancement Requirements (PAR) NAVPERS 1414/4 must be completed for advancement to E4 through E7.					
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATIONS**	Locally prepared tests.	See below.	Navywide examinations required for all PO advancements. Military leadership exam required for E-4 and E-5.			Plus selection board for E-7, E-8, and E-9.		
AUTHORIZATION	Commanding Officer		NAVEDTRAPRODEVCEN					

*Recommendation by commanding officer required for all advancements.
†Active duty periods may be substituted for training duty.
**For E-2 to E-3, NAVEDTRAPRODEVCEN exams or locally prepared tests may be used.

Figure 1-2.—Inactive duty advancement requirements.

WHO WILL BE ADVANCED?

Advancement is not automatic. Meeting all of the requirements makes you eligible but does not guarantee your advancement. Some of the factors that determine which persons of all of those qualified will actually be advanced in rate are:

1. The score made on the advancement examination.
2. The length of time in service.
3. The performance marks earned.
4. The number of vacancies available in a given rate.

If the number of vacancies in a given rate exceeds the number of qualified personnel, then all of those qualified will be advanced. More often, there are more qualified people than there are vacancies. When this happens, the Navy advances those who are BEST qualified by combining three personnel evaluation systems:

1. Merit rating system (semiannual evaluation and commanding officer recommendation).
2. Personnel testing system (advancement examination score—with some credit for passing previous advancement exams).
3. Longevity (seniority) system (time in rate and time in service).

Simply stated, each individual is given credit for what he or she has achieved in the three series of performance, knowledge, and seniority. A composite, known as the final multiple score, is derived from these three factors. All of the candidates who have passed the examination from a given advancement population are then placed on one list. Based on the final multiple score, the person with the highest multiple score is ranked first, and so on, down to the person with the lowest multiple score. Advancement authorizations are then issued for candidates for E4, E5, and E6, beginning at the top of the list, for the number of persons needed to fill the existing vacancies. Candidates for E7 whose final multiple scores are high enough will be designated PASS SELBD ELIG (Pass Selection Board Eligible). Their names will be placed before the Chief Petty Officer Selection Board, a BUPERS board charged with considering all so-designated eligible candidates for advancement to CPO. Advancement authorizations for those being advanced to CPO are issued by this board.

Who, then, are the individuals who are advanced? Basically, they are the ones who achieved the most in preparing for advancement. They were not content to just qualify; they expended extra effort in their training. Through that training and their work experience they developed greater skills, learned more, and accepted more responsibility.

While it cannot guarantee that any one person will be advanced, the advancement system does guarantee that all persons within a particular rating will compete equally for the vacancies that exist.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement?

1. Learn the naval standards for your paygrade level.
2. Learn how to perform the work defined by the occupational standards for your rating.
3. Work on the Personnel Advancement Requirement (PAR) Program for your rating.
4. Study the required rate training manuals for your rating.
5. Study other material applicable for advancement in your rating such as shown in the *Bibliography for Advancement Study*, NAVEDTRA 10052. (NOTE: If you are working for advancement to second class, remember that you may be examined on third class standards as well as on second class standards.

The following sections describe these five factors and give you some practical suggestions on how to use them in preparing for advancement.

Naval Standards

Naval standards are requirements that apply to all ratings rather than to any one particular rating. Naval requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watchstanding, and other subjects which are required of petty officers in all ratings.

You are required to pass a Navywide military/leadership examination for E-4 or E-5, as appropriate, before you take the professional examinations. The military/leadership examinations are administered on a schedule determined by your commanding officer. Candidates are required to pass the applicable military/leadership examination only once. Each of these examinations consists of 100 questions based on information contained in *Military Requirements for Petty Officers 3 & 2*, NAVEDTRA 10056 (current edition) and in other publications listed in the *Bibliography for Advancement Study*, NAVEDTRA 10052 (current edition).

Occupational Standards

Occupational Standards are requirements that are directly related to the work of each rating.

Both the naval standards and the occupational standards are divided into subject matter groups.

The *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068-D has replaced the "quals manual" and the NEC manual. Section I contains the occupational and naval standards for advancement to each paygrade in each enlisted rating. Section II contains the Navy Enlisted Classification Codes.

Advancement Examinations

The Navywide advancement examinations for paygrades E-4 and E-5 contain 150 questions related to the occupational areas of your rating.

On the day you take your advancement examination, your examination proctor will announce that you are to remove the last sheet of your test booklet and give it to him. This last page of your booklet is the Exam Information Sheet, shown in figure 1-3, and on the reverse side is the Profile Form Information Sheet, shown in figure 1-4. When you turn in your examination, the sheet will be returned for you to keep.

Several weeks after your examination, you should receive a profile card similar to the one shown inside the black frame in figure 1-4. Suppose your profile card (fig. 1-4) shows a "P" on section 5 (see the arrow) of the examination; you should then refer back to the Exam Information Sheet, figure 1-3. If you then compared section 5 on the profile card to the section of figure 1-3 marked by the marginal arrow, you would fine the subject, Telescopes. Since you had received a "P" for poor on this section, study would appear necessary on that subject and standards before your next examination.

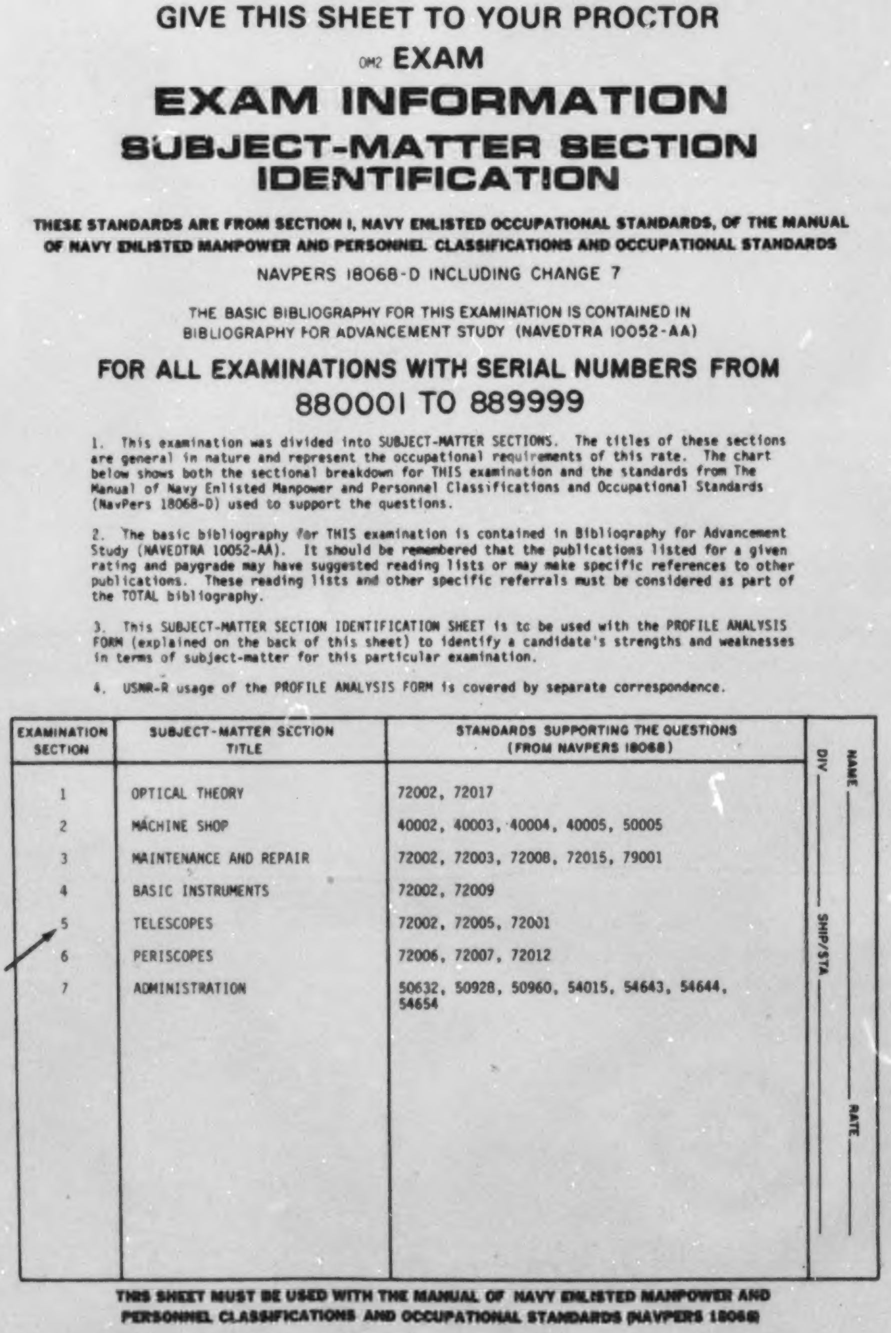
Your Education Services Officer should be able to furnish you with a standards and bibliography sheet for each examination you are to take. This bibliography will cite the publications used in examination development. These sheets along with your profile card and Exam Information Sheet will help you plan your study for examinations.

PERSONNEL ADVANCEMENT REQUIREMENT (PAR) PROGRAM, NAVPERS 1414/4

The Personnel Advancement Requirement (PAR) is a new system of evaluation that replaces the Record of Practical Factors, NAVEDTRA 1414/1. The PAR is based on the new occupational standards and is presented in task statements, whereas the old Record of Practical Factors was stated in terms of practical factors and knowledge factors which required lengthy and detailed checkoff lists. The PAR allows a command to evaluate the overall abilities of an individual in a day-to-day work situation.

The E-8 and E-9 paygrades are exempted from the program because there are other means of selection for advancement to these paygrades. Also, the E-3 apprenticeships are so broad that it is impractical to develop a single PAR for this paygrade.

The PAR for each rating lists the requirements for advancement to paygrades E-4 through E-7 in one pamphlet. The PAR is



GIVE THIS SHEET TO YOUR PROCTOR

OM2 **EXAM**

EXAM INFORMATION

SUBJECT-MATTER SECTION IDENTIFICATION

THESE STANDARDS ARE FROM SECTION I, NAVY ENLISTED OCCUPATIONAL STANDARDS, OF THE MANUAL OF NAVY ENLISTED MANPOWER AND PERSONNEL CLASSIFICATIONS AND OCCUPATIONAL STANDARDS

NAVPERS 18068-D INCLUDING CHANGE 7

THE BASIC BIBLIOGRAPHY FOR THIS EXAMINATION IS CONTAINED IN BIBLIOGRAPHY FOR ADVANCEMENT STUDY (NAVEDTRA 10052-AA)

FOR ALL EXAMINATIONS WITH SERIAL NUMBERS FROM

880001 TO 889999

1. This examination was divided into SUBJECT-MATTER SECTIONS. The titles of these sections are general in nature and represent the occupational requirements of this rate. The chart below shows both the sectional breakdown for THIS examination and the standards from The Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards (NavPers 18068-D) used to support the questions.

2. The basic bibliography for THIS examination is contained in Bibliography for Advancement Study (NAVEDTRA 10052-AA). It should be remembered that the publications listed for a given rating and paygrade may have suggested reading lists or may make specific references to other publications. These reading lists and other specific referrals must be considered as part of the TOTAL bibliography.

3. This SUBJECT-MATTER SECTION IDENTIFICATION SHEET is to be used with the PROFILE ANALYSIS FORM (explained on the back of this sheet) to identify a candidate's strengths and weaknesses in terms of subject-matter for this particular examination.

4. USNR-R usage of the PROFILE ANALYSIS FORM is covered by separate correspondence.

EXAMINATION SECTION	SUBJECT-MATTER SECTION TITLE	STANDARDS SUPPORTING THE QUESTIONS (FROM NAVPERS 18068)
1	OPTICAL THEORY	72002, 72017
2	MACHINE SHOP	40002, 40003, 40004, 40005, 50005
3	MAINTENANCE AND REPAIR	72002, 72003, 72008, 72015, 79001
4	BASIC INSTRUMENTS	72002, 72009
5	TELESCOPES	72002, 72005, 72001
6	PERISCOPES	72006, 72007, 72012
7	ADMINISTRATION	50632, 50928, 50960, 54015, 54643, 54644, 54654

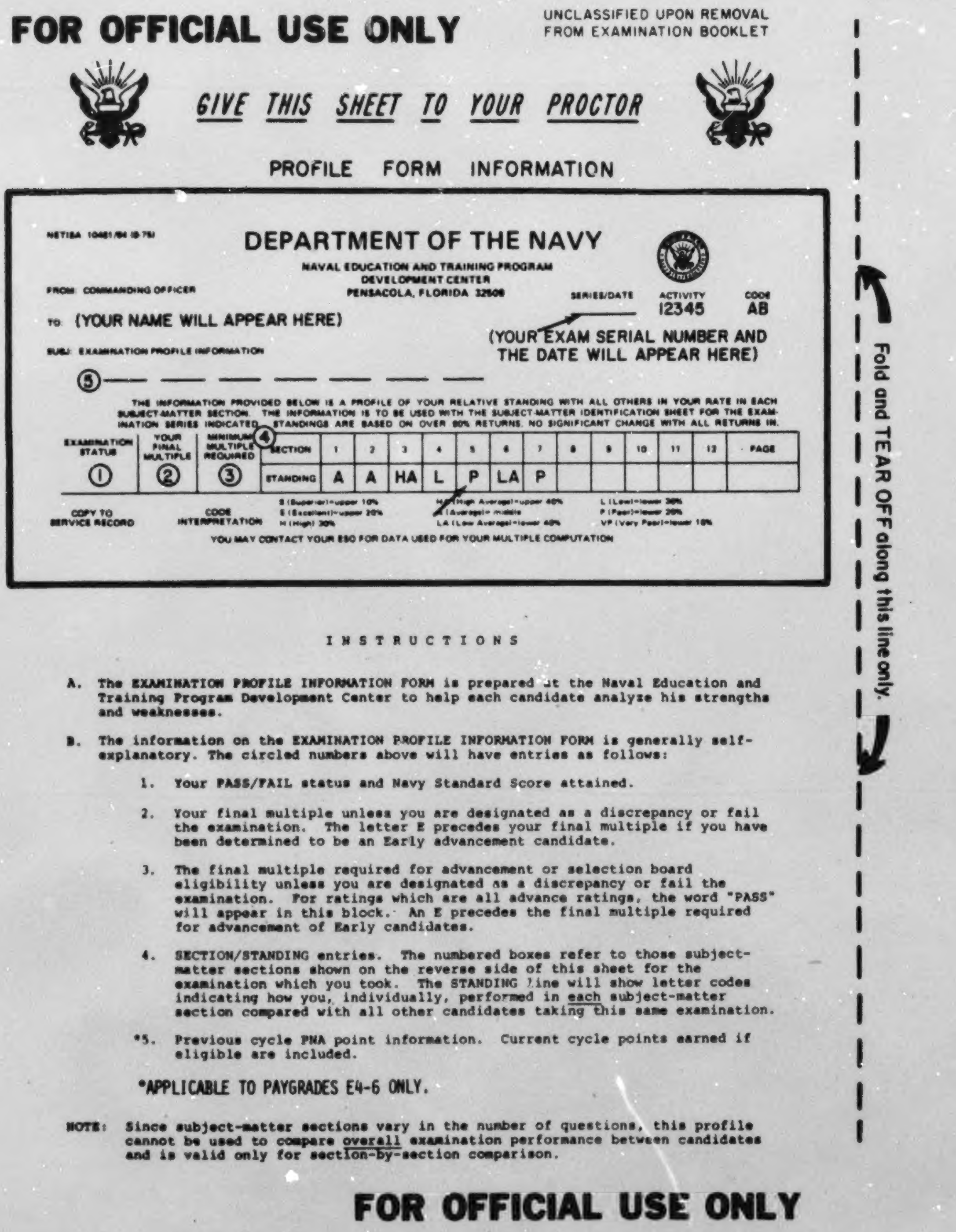
NAME ____________ RATE ____________

DIV ____________ SHIP/STA ____________

THIS SHEET MUST BE USED WITH THE MANUAL OF NAVY ENLISTED MANPOWER AND PERSONNEL CLASSIFICATIONS AND OCCUPATIONAL STANDARDS (NAVPERS 18068)

137.554

Figure 1-3.—Exam Information Sheet.



FOR OFFICIAL USE ONLY

UNCLASSIFIED UPON REMOVAL
FROM EXAMINATION BOOKLET

GIVE THIS SHEET TO YOUR PROCTOR

PROFILE FORM INFORMATION

NETISA 10481/84 (9-75)

DEPARTMENT OF THE NAVY

NAVAL EDUCATION AND TRAINING PROGRAM
DEVELOPMENT CENTER
PENSACOLA, FLORIDA 32508

FROM: COMMANDING OFFICER

TO: (YOUR NAME WILL APPEAR HERE)

SUBJ: EXAMINATION PROFILE INFORMATION

SERIES/DATE ______ ACTIVITY 12345 CODE AB

(YOUR EXAM SERIAL NUMBER AND THE DATE WILL APPEAR HERE)

⑤ ___ ___ ___ ___ ___ ___ ___

THE INFORMATION PROVIDED BELOW IS A PROFILE OF YOUR RELATIVE STANDING WITH ALL OTHERS IN YOUR RATE IN EACH SUBJECT-MATTER SECTION. THE INFORMATION IS TO BE USED WITH THE SUBJECT-MATTER IDENTIFICATION SHEET FOR THE EXAMINATION SERIES INDICATED. STANDINGS ARE BASED ON OVER 90% RETURNS. NO SIGNIFICANT CHANGE WITH ALL RETURNS IN.

EXAMINATION STATUS	YOUR FINAL MULTIPLE	MINIMUM MULTIPLE REQUIRED	④ SECTION	1	2	3	4	5	6	7	8	9	10	11	12	PAGE
①	②	③	STANDING	A	A	HA	L	P	LA	P						

COPY TO SERVICE RECORD

CODE INTERPRETATION

S (Superior)=upper 10%
E (Excellent)=upper 20%
H (High) 30%
HA (High Average)=upper 40%
A (Average)= middle
LA (Low Average)=lower 40%
L (Low)=lower 30%
P (Poor)=lower 20%
VP (Very Poor)=lower 10%

YOU MAY CONTACT YOUR ESO FOR DATA USED FOR YOUR MULTIPLE COMPUTATION

Fold and TEAR OFF along this line only.

INSTRUCTIONS

A. The **EXAMINATION PROFILE INFORMATION FORM** is prepared at the Naval Education and Training Program Development Center to help each candidate analyze his strengths and weaknesses.

B. The information on the **EXAMINATION PROFILE INFORMATION FORM** is generally self-explanatory. The circled numbers above will have entries as follows:

1. Your PASS/FAIL status and Navy Standard Score attained.
2. Your final multiple unless you are designated as a discrepancy or fail the examination. The letter E precedes your final multiple if you have been determined to be an Early advancement candidate.
3. The final multiple required for advancement or selection board eligibility unless you are designated as a discrepancy or fail the examination. For ratings which are all advance ratings, the word "PASS" will appear in this block. An E precedes the final multiple required for advancement of Early candidates.
4. SECTION/STANDING entries. The numbered boxes refer to those subject-matter sections shown on the reverse side of this sheet for the examination which you took. The STANDING line will show letter codes indicating how you, individually, performed in each subject-matter section compared with all other candidates taking this same examination.

*5. Previous cycle PNA point information. Current cycle points earned if eligible are included.

*APPLICABLE TO PAYGRADES E4-6 ONLY.

NOTE: Since subject-matter sections vary in the number of questions, this profile cannot be used to compare overall examination performance between candidates and is valid only for section-by-section comparison.

FOR OFFICIAL USE ONLY

137.555

Figure 1-4.—Profile Form Information Sheet.

comprised of three sections which contain descriptive information, instructions for administration, special rating requirements, and advancement requirements.

Section I–Administration Requirements–contains the individual's length of service, time in paygrade, and a checkoff for the individual's having passed the E-4/E-5 military/leadership examination.

Section II–Formal School and Training Requirements–contains a checkoff entry for the individual's having completed the Military Requirements Navy Training Course and the applicable Navy Training Course for the rating.

Section III–Occupational and Military Ability Requirements–is a checkoff list of task statements. Items in this section are to be interpreted broadly and do not demand actual demonstration of the item nor completion of alternate local examination, although demonstration is a command prerogative. Individuals are evaluated by observation of their ability to perform tasks in related areas by training received or, if desired, by demonstration.

PAR forms are stocked in the Navy Supply System.

PERSONNEL QUALIFICATION STANDARDS

The Personnel Qualification Standard is a document which describes the knowledge and skills a trainee must have to correctly perform certain duties. It will speed up learning progress since each person will know exactly what information to obtain to qualify for increasingly complex duties. It individualizes learning so that each person may take advantage of opportunities to learn on the job. It places the responsibilities for learning on the learner and encourages self-achievement. By providing a convenient record of accomplishment, it offers a means whereby supervisors can check individual speed and manner of performance.

Since the Personnel Qualification Standards have been assembled by groups of experienced officers and petty officers, they attempt to represent the guidance which would be furnished if each person had an individual instructor throughout each step.

Personnel Qualification Standards are designed to support advancement in rating requirements as stated in the *Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* (NAVPERS 18068 series.)

Every Personnel Qualification Standard contains the following sections:

1. Introduction
2. Glossary of Qualification Standard Terms
3. Table of Contents
4. 100 series – Theory
5. 200 series – Systems
6. 300 series – Watchstanding
7. 400 series – Qualification Cards
8. Bibliography
9. Feedback Forms

PURPOSES, BENEFITS, AND LIMITATIONS OF THE PLANNED MAINTENANCE SYSTEM

PURPOSES

The Planned Maintenance System (PMS) was established for several purposes:

1. To reduce complex maintenance to simplified procedures that are easily identified and managed at all levels.
2. To define the minimum planned maintenance required to schedule and control PMS performances.
3. To describe the methods and tools to be used.
4. To provide for the detection and prevention of impending casualties.
5. To forecast and plan manpower and material requirements.
6. To plan and schedule maintenance tasks.
7. To estimate and evaluate material readiness.
8. To detect areas requiring additional or improved personnel training and/or improved maintenance techniques or attention.
9. To provide increased readiness of the ship.

BENEFITS

PMS is a tool of command. By using PMS, the Commanding Officer can readily determine whether the ship is being properly maintained. Reliability is intensified. Preventive maintenance reduces the need for major corrective maintenance, increases economy, and saves the cost of repairs.

PMS assures better records, containing more data that can be useful to the shipboard maintenance manager. The flexibility of the system allows for programming of inevitable changes in employment schedules, thereby helping to better plan preventive maintenance.

Better leadership and management can be realized by reducing frustrating breakdowns and irregular hours of work. PMS offers a means of improving morale and thus enhances the effectiveness of both enlisted personnel and officers.

LIMITATIONS OF PMS

The Planned Maintenance System is not self-starting; it will not automatically produce good results; considerable professional guidance is required. Continuous direction at each echelon must be maintained, and one individual must be assigned both the authority and the responsibility at each level of the system's operation.

Training in the maintenance steps as well as in the system will be necessary. No system is a substitute for the actual technical ability required of the officers and enlisted personnel who direct and perform upkeep of the equipment.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the naval requirements for advancement and the occupational standards of your rating.

In this section we shall discuss most of the publications you will use. The detailed information you need for advancement and for everyday work is contained in them. Some are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you to do your work or to advance in rate. At best, it is a waste of time; at worst, it is likely to be dangerously misleading.

NAVEDTRA PUBLICATIONS

Rate training manuals, nonresident career courses and other training texts and courses to help you become more knowledgeable in your career field are prepared by the Naval Education and Training Program Development Center. Since this center is a field activity of the Chief of Naval Education and Training, these training materials are designated as NAVEDTRA publications. Some training materials still are designated as NAVPERS or NAVTRA publications, but as they are updated their designations will be changed to NAVEDTRA.

The naval training publications described herein include some that are absolutely essential for anyone seeking advancement and some that, although not essential, are extremely helpful.

NAVEDTRA 10052

Bibliography for Advancement Study, NAVEDTRA 10052 is a very important publication for any enlisted person preparing for advancement. It lists required and recommended rate training manuals and other reference materials to be used by personnel working for advancement. Especially important are the listed manufacturer's technical manuals.

NAVEDTRA 10052 is revised and issued annually by the Chief of Naval Education and Training. Each revised edition is identified by a letter following the NAVEDTRA number. When using this publication, be sure that you have the most recent edition.

If extensive changes in standards occur in any rating between the annual revisions of NAVEDTRA 10052, a supplementary list of study material may be issued in the form of a BUPERS Notice. When you are preparing for advancement, check to see whether changes have been made in the standards for your rating. If changes have been made, see whether a BUPERS Notice has been issued to supplement NAVEDTRA 10052 for your rating.

The required and recommended references are listed by paygrade in NAVEDTRA 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class, but remember that you are also responsible for the references listed at the third class level.

In using NAVEDTRA 10052, you will notice that some rate training manuals are marked with an asterisk (*). Any manual marked in this way is MANDATORY–that is, you must complete it at the indicated rate level before you can be eligible to take the Navywide examination for advancement. Each mandatory manual may be completed by (1) passing the appropriate nonresident career course that is based on the mandatory training manual; (2) passing locally prepared tests based on the information given in the training manual; or (3) in some cases, successfully completing an appropriate naval school.

Do not overlook the section of NAVEDTRA 10052 which lists the required and recommended references relating to the naval standards for advancement. Personnel of ALL ratings must complete the mandatory military requirements training manual for the appropriate rate level before they are eligible to advance.

The references in NAVEDTRA 10052 which are recommended but not mandatory should also be studied carefully. All references listed in NAVEDTRA 10052 may be used as source material for the written examinations, at the appropriate rate levels.

Besides training manuals, NAVEDTRA 10052 lists official publications on which you may be examined. You should not only study the sections required, but should become as familiar as possible with all publications you use.

Rate Training Manuals

There are two general types of rate training manuals. RATING manuals (such as this one) are prepared for most enlisted ratings. A rating manual gives information that is directly related to the occupational standards of one rating. SUBJECT MATTER manuals or BASIC manuals give information that applies to more than one rating.

Rate training manuals are revised from time to time to keep them up-to-date technically. The revision of a rate training manual is identified by a letter following the NAVEDTRA number. You can tell whether any particular copy of a training manual is the latest edition by checking the NAVEDTRA number and the letter following this number in the most recent edition of *List of Training Manuals and Correspondence Courses*, NAVEDTRA 10061. (NAVEDTRA 10061 is actually a catalog that lists all current training manuals and courses; you will find this catalog useful in planning your study program.)

Each time a rate training manual is revised, it is brought into conformance with the official publications and directives on which it is based. However, during the life of any edition of a rate training manual, changes will be made to the official sources and discrepancies will arise. In the performance of your duties, you should always refer to the appropriate official publication or directive. If the official source is listed in NAVEDTRA 10052, the Naval Education and Training Program Development Center uses it as a source of questions in preparing the fleetwide examinations for advancement. In case of discrepancy between any publications listed in NAVEDTRA 10052 for a given rate, the examination writers will use the most recent material.

Rate training manuals are designed to help you prepare for advancement. The following suggestions may help you to make the best use of this manual and other Navy training publications when you prepare for advancement.

1. Study the naval standards and the occupational standards for your rating before

you study the training manual and refer to the standards frequently as you study. Remember, you are studying the manual primarily to meet these standards.

2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you can plan to study at the same time each day. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the manual intensively, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Thumb through the book without any particular plan. Look at the illustrations and read bits here and there as you see things that interest you. A table on conversion to the metric system appears in Appendix I for your convenience.

4. Look at the training manual in more detail to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. In this manner you will get a pretty clear picture of the scope and content of the book. As you look through the book, ask yourself some questions:

What do I need to learn about this?
What do I already know about this?
How is this information related to information given in other chapters?
How is this information related to the occupational standards?

5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will vary. If you know the subject well or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying any one unit—chapter, section, or subsection—write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the training manual, write down the main ideas that you have gotten from studying this unit. Don't just quote the book. If you can't give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use nonresident career courses whenever you can. The courses are based on rate training manuals or on other appropriate texts. As mentioned before, completion of a mandatory rate training manual can be accomplished by passing a nonresident career course based on the rate training manual. You will probably find it helpful to take other courses, as well as those based on mandatory manuals. Taking a course helps you to master the information given in the training manual and also helps you to see how much you have learned.

10. Think of your future as you study rate training manuals. You are working for advancement to third class or second class right now, but some day you will be working toward higher rates. Anything extra that you can learn now will also help you later.

CHAPTER 2

THE NATURE OF LIGHT

Since the dawn of civilization, the real nature of light and the way it travels has aroused curiosity. The answer to the question, "What Is Light?" has changed several times in the past 300 years and we are still experimenting, looking for the scientific facts that will give a true answer.

There is no single theory that explains all of the characteristics of light. Because of space limitation, we can discuss only some of the theories and known facts of light behavior, but enough to give you an idea of their impact on the development of current theories.

THEORIES OF LIGHT

Scientists throughout the centuries have developed various theories concerning light. The ancient Greeks, for example, believed that light was generated by streams of particles ejected from the eyes and was then reflected back into the eyes from objects they struck. This was the theory of generated particles which did not last long because it did not explain why a person could not see as well by night as by day.

PARTICLES AND WAVES

In the latter part of the eighteenth century, two new schools of thought emerged. Issac Newton believed light to be a flight of material particles originating from a source of light. Christian Huygens and other physicists believed the theory that light energy was a product of wave motion. The argument between supporters of the particles theory and supporters of the wave theory has continued into our modern times.

Corpuscular Theory

In 1704, Newton published a book, *OPTICKS*, in which he described light as a stream of particles called corpuscles. From this, his theory became known as the corpuscular theory. One of the primary arguments which supported the particle theory of light was that light travels in a straight line. Since waves created on water cause a disturbance around an obstacle and since sound can be heard around the corner of a building, particle supporters would not believe that light was a wave phenomenon.

Ether Theory

Huygens is generally considered the founder of the wave theory of light, and his basic concept is still very useful in predicting the behavior of light. Although Huygens' theory of wave motion appeared to be the logical explanation for some phases of light behavior, it was not accepted for many years. Huygens could explain the passage of waves through water, but he could not explain how light waves from the sun passed through space. To explain this mystery, he proposed that light passed through a medium that occupied all space which he called ETHER. He assumed that ether even occupied space that was already occupied by matter.

About 50 years after Huygens announced his theory of wave motion of light, Thomas, Young, Fresnel, and others supported the wave theory, and Newton's corpuscular theory was virtually abandoned. These three scientists accepted the ether theory and assumed that light was waves of energy transmitted by an elastic medium designated by Huygens as ether.

ELECTROMAGNETIC THEORY

Three other scientists (Boltzmann, Hertz, and Maxwell) conducted experiments which proved that light and electricity are similar in radiation and speed. As a result of their experiments, they developed the electromagnetic theory. They produced alternating electric currents with short wavelengths which were undoubtedly of electromagnetic origin and had all the properties of light waves. This theory, sometimes called the Maxwell theory, held that energy was given off continuously by the radiating body.

For some years after the introduction of the Maxwell theory of light, scientists thought the puzzle of light was definitely solved. In 1900, however, Max Planck rejected the electromagnetic theory. He did not believe that energy from a radiating body was given off continuously. He contended that the radiating body contained a large number of tiny oscillators, possibly resulting from electrical action of atoms within the body; his idea was that the energy given off by the body could be of high frequency and have high energy value, with all possible frequencies represented. Planck argued that the higher the temperature of the radiating body, the shorter would be the wavelengths of most energetic radiation.

QUANTUM THEORY

To account for the manner in which radiation from a warm, blackbody is distributed among the different wavelengths, Planck found an equation to fit the experimental curves, which were based on lightwaves of different lengths. He concluded that the small particles of radiated energy were GRAINS of energy like grains of sand. He therefore called these units quanta and named his theory the quantum theory. He assumed that when quanta were set free they moved from their source in waves.

Five years later, Albert Einstein backed up Planck with some complex mathematical equations. He showed that quanta somehow manage to have a frequency, like waves. But the quanta are particles, just the same.

Experiments by R. A. Millikan proved that Einstein's equations were correct. In 1921, A. H. Compton studied the motion of the electron and the light quantum, both before and after their collision. He found that particles of light have momentum and kinetic energy, just like particles of matter, which brings us right back to the corpuscular theory again.

Knowledge gained later by scientists from the study of diffraction, interference, polarization, and velocity (discussed later) proved the corpuscular theory of light untenable. More recently, however, phenomena of light have been discovered which are not accounted for by the wave theory, so many scientists now accept Maxwell's electromagnetic theory.

Spectroscopy and the laser have given scientists valuable tools with which to experiment, and the results of these experiments are causing scientists to review all previous theories of light. Although not conclusive, there is strong evidence to support the belief that light is a combination of the quantum theory and the electromagnetic theory.

Before a theory concerning light propagation can be accepted, it must prove all the phenomena of light propagation. Since we lack a proven theory, we have no choice but to accept the theory that best explains the passage of light through an optical instrument. This is the wave theory which will be used for all discussions of light in this manual.

SOURCES OF LIGHT

All of our lives we have been aware that the sun is our greatest source of light. The sun and all other sources of light, regardless of the amount that they give off, are considered to be luminous bodies because they emit energy in the form of visible light. All luminous bodies are placed in one of two categories, natural or artificial.

NATURAL

The only sources of natural light are the sun, which is 93,000,000 miles away, and the stars. Even though lightning, volcanic activity, and certain vegetable or insect luminescence are actually natural light, they are not relevant to the study of optics.

ARTIFICIAL

From the previous statement, you can easily understand that all light which does not come from the sun or the stars is artificial light. This covers all light from the first fire on earth to the modern laser. Man has made many artificial light sources since Thomas Edison invented the first incandescent bulb, and with today's neon and fluorescent lights, we have a wide variety of colors and intensities from which to choose.

Illuminated Bodies

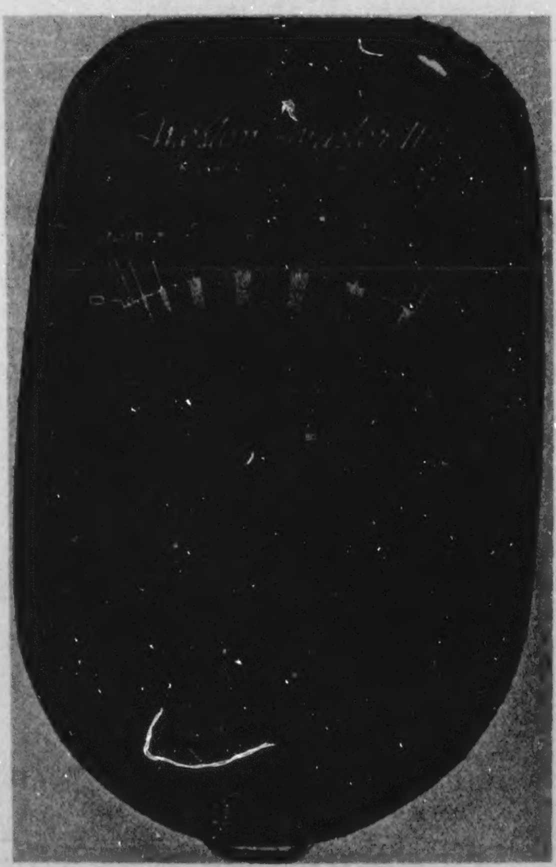
Any object that we are able to see, because of the light energy reflected from its surface, is called an illuminated body. The moon, because it reflects light from the sun, is an illuminated body. The book that you are now reading is an illuminated body because it reflects light energy, whether it is from a natural source or an artificial source.

Intensity of Illumination

Illumination is simply the act of casting light energy. The intensity of the amount of light energy that is given off is a major factor in determining how well we are able to see an object. We know very well that at night, when there is little light available, it is difficult to distinguish objects.

In determining the intensity of illumination, we measure the light energy coming from the luminous or illuminated body. One way to do this is with the exposure meter used by photographers (fig. 2-1). All you need to do is turn the meter toward a light source or an illuminated body and observe the movement of the hand. Although the meter has no internal source of power and the indicating needle has a spring acting against it, the needle will move when light strikes the sensing element. This is a good indication of the energy of light.

The unit used for measuring the intensity of light is called CANDLEPOWER, or LUMEN. If a luminous source, for example, gives ten times as much illumination as a standard candle, it has the intensity of 10 candlepower.



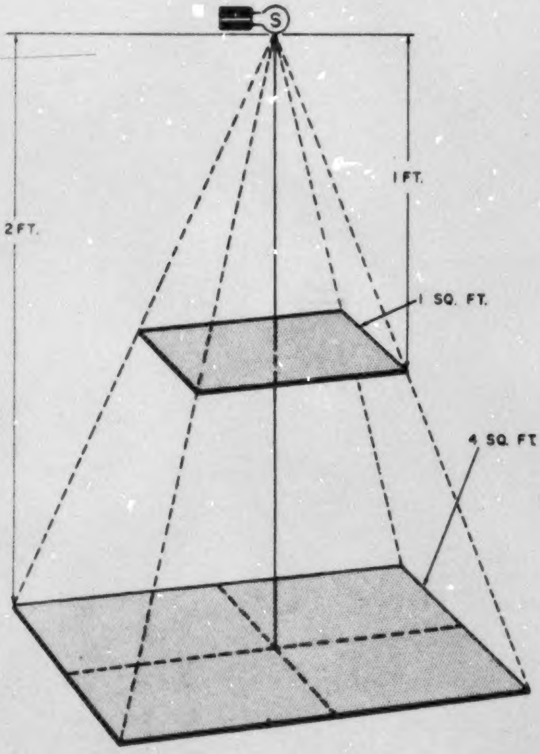
137.3

Figure 2-1.—Electric exposure meter.

Because of the difficulty in getting exact measurements with a standard such as a candle, the National Bureau of Standards maintains a group of incandescent electric lights which fulfill certain conditions as standards of measurement. Secondary standards can be calibrated from these standard lamps by any laboratory.

The amount of light which falls on a nonluminous source is generally measured in FOOT-CANDLES, or luminous flux.

The surface of an object is illuminated by 1 foot-candle when its light source is 1



137.12

Figure 2-2.—The inverse square law of light.

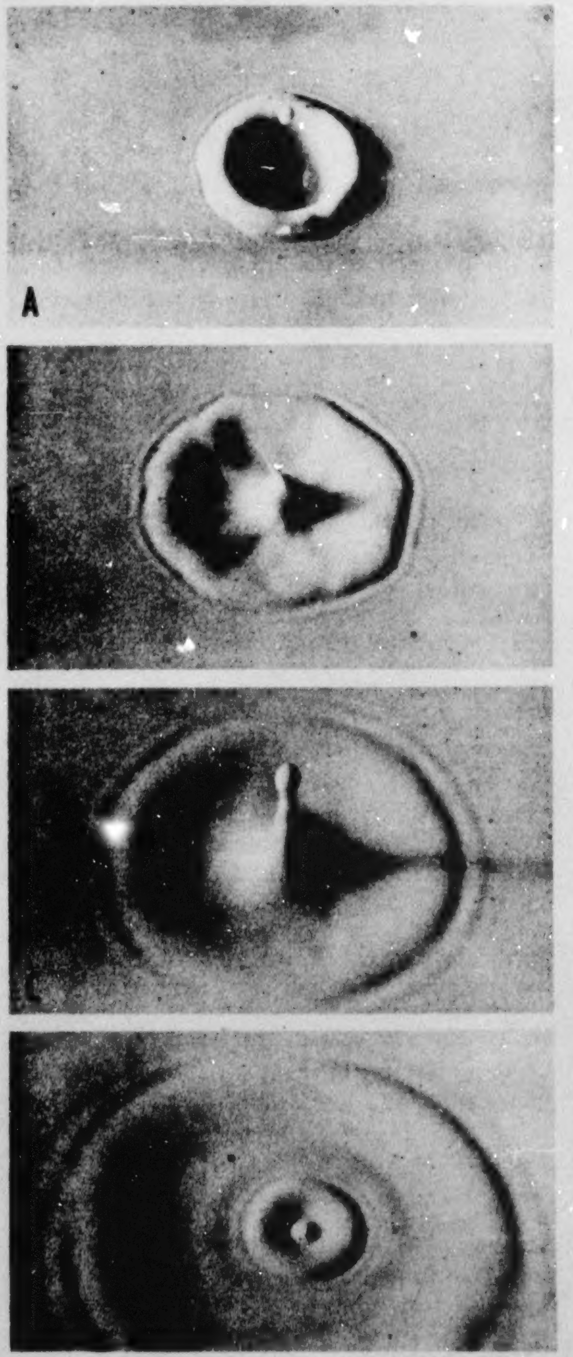
candlepower at a distance of 1 foot. The formula for this is:

$$\text{Foot-Candles} = \frac{\text{Candlepower}}{(\text{Distance})^2}$$

Look now at figure 2-2. If the object is 2 feet from the light source, the light from the lamp covers four times the area it covered after traveling 1 foot. The illumination at this point is only one-fourth of a foot-candle. Illumination provided by a source is therefore inversely proportional to the square of the distance between the source and the object.

Wave Energy

The pictures in illustration 2-3 were taken a fraction of a second apart. Note in part A that



137.4

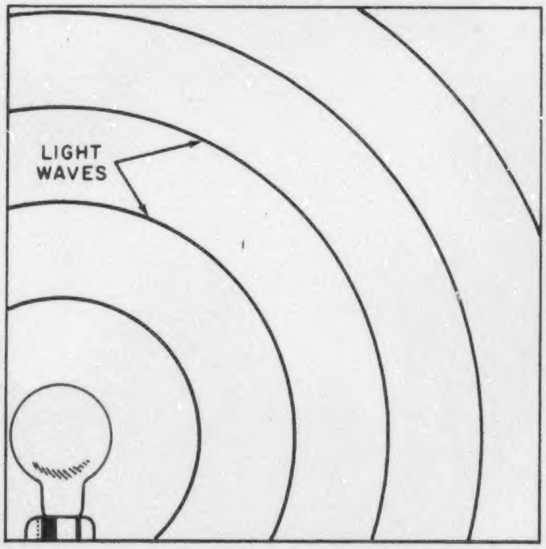
Figure 2-3.—Creation of waves in a liquid by a dropped pebble.

the pebble made a dent in the solution (milk) and that the surface is recovering its natural position and is rising. Part B shows that the surface of the milk has begun to rise and that the original wave is beginning to spread. Energy is spreading out in the form of little waves on the surface of the milk from the source of the disturbance caused by the pebble. The waves are circles which get bigger and bigger as the amount of energy (wave motion) created by the pebble causes them to expand–the bigger the pebble, the greater the size of the waves and circles. When all the energy produced on the milk by the pebble is absorbed by the waves, they stop forming, as illustrated.

During the latter part of the 18th century, scientists found that radiation from hot bodies consists of electromagnetic waves (not mechanical). This type radiation is called thermal radiation. Thermal radiation of light waves are of the same nature and exhibit similar properties. Like light waves, thermal radiation normally travels in straight lines and can be reflected from a mirror or polished metal. Thermal radiation is not heat; it is energy in the form of wave motion.

Luminous light sources such as the sun or the glowing filament of an electric light bulb act as oscillators in radiating energy in the form of light waves, and these waves spread out in all directions from their sources. The sun pours forth radiant energy from its surface at the rate of 70,000 horsepower for every square yard of its surface.

Because light travels outward in all directions from its source, the waves take the form of growing spheres (fig. 2-4), the luminous point of which is the center.



137.7

Figure 2-4.–Light waves created by a light.

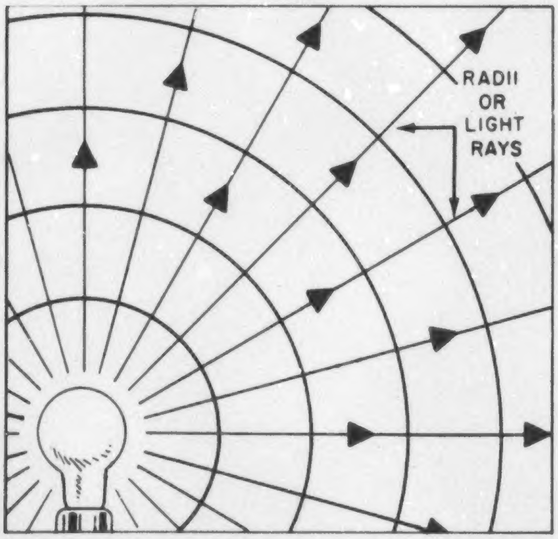
TRANSMISSION OF LIGHT

We know now that all forms of light obey the same general laws. When light travels through a medium or substance of constant optical density, it travels in waves in straight lines and at a constant speed. When light strikes a different medium from the one through which it is traveling, it is either reflected from, or enters, the medium. Upon entering a transparent medium, the speed of light is slowed down if the medium is MORE dense, or increased if the medium is LESS dense. Some substances of moderate density have abnormal optical properties and, for this reason, they may be designated as optically dense. If the light strikes the medium on an angle, its course is bent (refracted) as it enters the medium. (Note: Reflection and refraction are discussed fully later in this chapter. However, in discussing the characteristics of light, we must use terms possibly unknown to you and explain them only to the extent necessary for you to understand the discussion.)

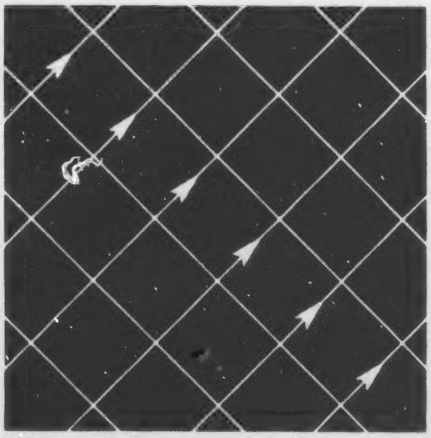
After you learn the characteristics of light and the types and functions of various optical elements, you will then experience less difficulty in understanding image formation–the prime purpose of optical instruments.

LIGHT RAYS

A basic problem in the design of optical systems is the calculation of wave surfaces as they progress through the various optical media. In optics, the calculation of wave surfaces is approached by taking a small number of rays and tracing these rays through the system.

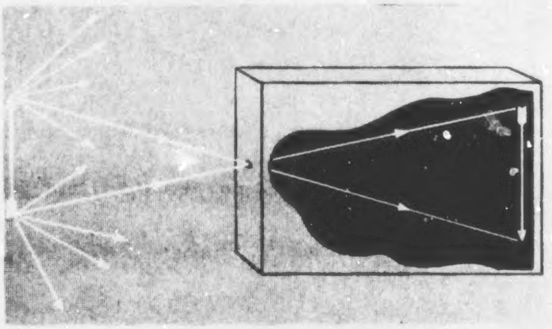


137.8
Figure 2-5.—Direction of travel of light waves.



137.10
Figure 2-6.—Waves and radii from a distant light.

Single rays of light do not exist; but the term light ray is used throughout this manual for the sake of clarity and convenience in showing the direction of travel of the wave front. Light is indicated by one, two, or more representative light rays in white lines with arrowheads to indicate the direction of travel.



137.11
Figure 2-7.—Light rays creating an image on the film of a pinhole camera.

Refer again to figure 2-4 and note that light is moving in all directions from the light bulb. Then study figure 2-5 which shows lines with arrowheads to indicate that the direction of travel of the light is along the radii of the sphere of light waves and at right angles to the fronts of the waves. The light which travels along these radii is designated as light rays.

A wave front radiating from a light source is extremely curved near the light source which causes the radii of the sphere of the waves to diverge, or spread. As the wave front moves outward, however, it becomes less curved the farther it travels from the light source and eventually appears to be almost straight, as indicated in figure 2-6. After traveling a distance of 2,000 yards from their light sources, radii are considered to be parallel to each other.

A pinhole camera (fig. 2-7) gives a good example of the manner in which light travels outward from its source. Such a camera is merely a box with a sheet of film at one end and a tiny pinhole instead of a lens at the other end. Note that the camera is taking a picture using light reflected from the arrow in front of the camera and that each point on the arrow is reflecting light rays in a dispersed manner. One ray of light from each point on the arrow enters the pinhole in the front of the camera and lands upon the film. Since light travels in straight lines, no light reaches a given point on the film except the ray which comes from the corresponding point on the arrow. The rays of light which pass through the pinhole of the camera form an inverted arrow on the film.

WAVELENGTH AND FREQUENCY

The action of waves on the surface of a liquid (fig. 2-3) has explained the wave motion of light, but to understand fully the speed at which light travels, you must comprehend the length of a wave and its frequency.

A wavelength is the distance between the crest on one wave and the crest of the next (adjacent) wave, as illustrated in figure 2-8. The best way to measure a wavelength is by the FREQUENCY–the number of waves which pass a point in 1 second. To determine frequency, put a stake in water and count the number of waves which pass the stake per second (fig. 2-9).

If waves are moving at a speed of 3 feet per second and have a frequency of 6 waves per second, you can determine the wavelength by using the formula that shows the relationship between the speed, frequency, and wavelength.

The formula is: $c = f\lambda$

where c = speed of light in a vacuum

f = frequency of waves

λ = wavelength (Greek letter lambda)

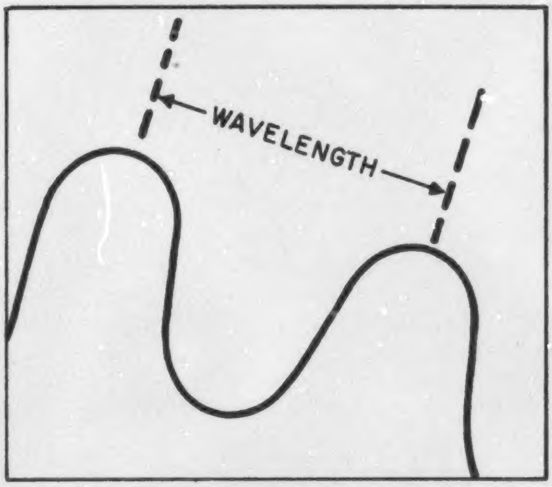
By applying the formula to the above problem, you get

$$3 = 6\lambda$$

$$\lambda = 3/6 = .5$$

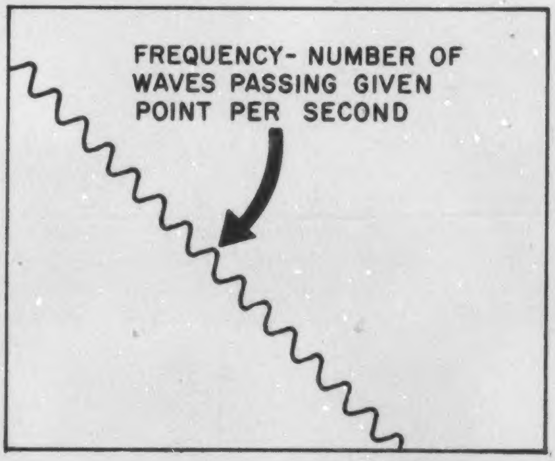
Light waves, in contrast with waves on water, are much too short to be measured in inches or millimeters. (A millimeter is about 1/25th of an inch.) A light wavelength is sometimes measured in microns, represented in formulas by μ. A micron is one-thousandth of a millimeter. For measuring a shorter wavelength of light, a smaller unit than a micron must be used. This unit is the MILLIMICRON, which represents one thousandth of a micron and is abbreviated $m\mu$.

Another important unit used for measuring wavelength is the ANGSTROM (AU), which is 1/10th of a millimicron, or one ten-millionth of a millimeter. Because these units are still inconveniently long for measuring the shortest electromagnetic waves, the X-ray unit is used for this purpose. It is one one-thousandth of an Angstrom unit.



137.14

Figure 2-8.—Measurement of a wavelength.



137.15

Figure 2-9.—Determination of wave frequency.

ELECTROMAGNETIC SPECTRUM

The electromagnetic spectrum may be divided into nine major regions of radiation, depending on the general character of the waves: (1) long electric waves, (2) radio waves, (3) radar, (4) infrared, (5) visible light, (6) ultraviolet, (7) X-rays, (8) gamma, and (9) cosmic rays. Together, all of these form the electromagnetic spectrum, illustrated in figure 2-10. The visible portion of the electromagnetic spectrum consists of wavelengths from .00038 to .00066 millimeters. The different wavelengths represent different colors of light. Note the arrows which point to the wavelengths of the colors of the rainbow in the spectrum. Observe also that the wavelengths in this part of the spectrum (vision and photography) are in millimicrons of wavelengths. Wavelengths in the electromagnetic spectrum (extreme left) are in microns.

In illustration 2-10 note that the wavelengths we call light are between 400 and 700 mμ; each spectral color has its own small range of wavelengths. For example, if light with a wavelength around 660 mμ reaches your eyes, you see RED (sensation of red on the retina). Around 400 mμ the wavelengths of light which reach your eyes are BLUE; so the red waves are therefore much longer than the blue waves.

When light with a wavelength of 300 mμ reaches your eyes, you receive no sensation of color. Radiation of this wavelength is generally called ULTRAVIOLET LIGHT. Ultraviolet rays (radiation) from the sun cause sunburn and sometimes blisters. CAUTION: All shortwave radiations can do some damage if you get too much of them. A prolonged dose of strong X-rays, for example, causes irreparable damage to the body. Gamma rays are deadly shortwave radiation given off by atomic particles. Note that the infrared light rays are between 1μ and 100μ in the electromagnetic spectrum. These rays are called HEAT rays. We cannot see infrared rays; but if we could see them, everything would look different. Study figure 2-11 which shows a photograph taken by visible light and figure 2-12 which shows a photograph of the scene taken with infrared film with a red filter over the lens.

Infrared light is used also for signaling between ships at night. In aerial reconnaissance, too, we use infrared photography to get more and better details of the area photographed. A camouflaged object, for example, may blend with its surroundings and be invisible from the air; but if it does not reflect the same amount of infrared as its surroundings, an infrared photograph will make the camouflage stand out clearly.

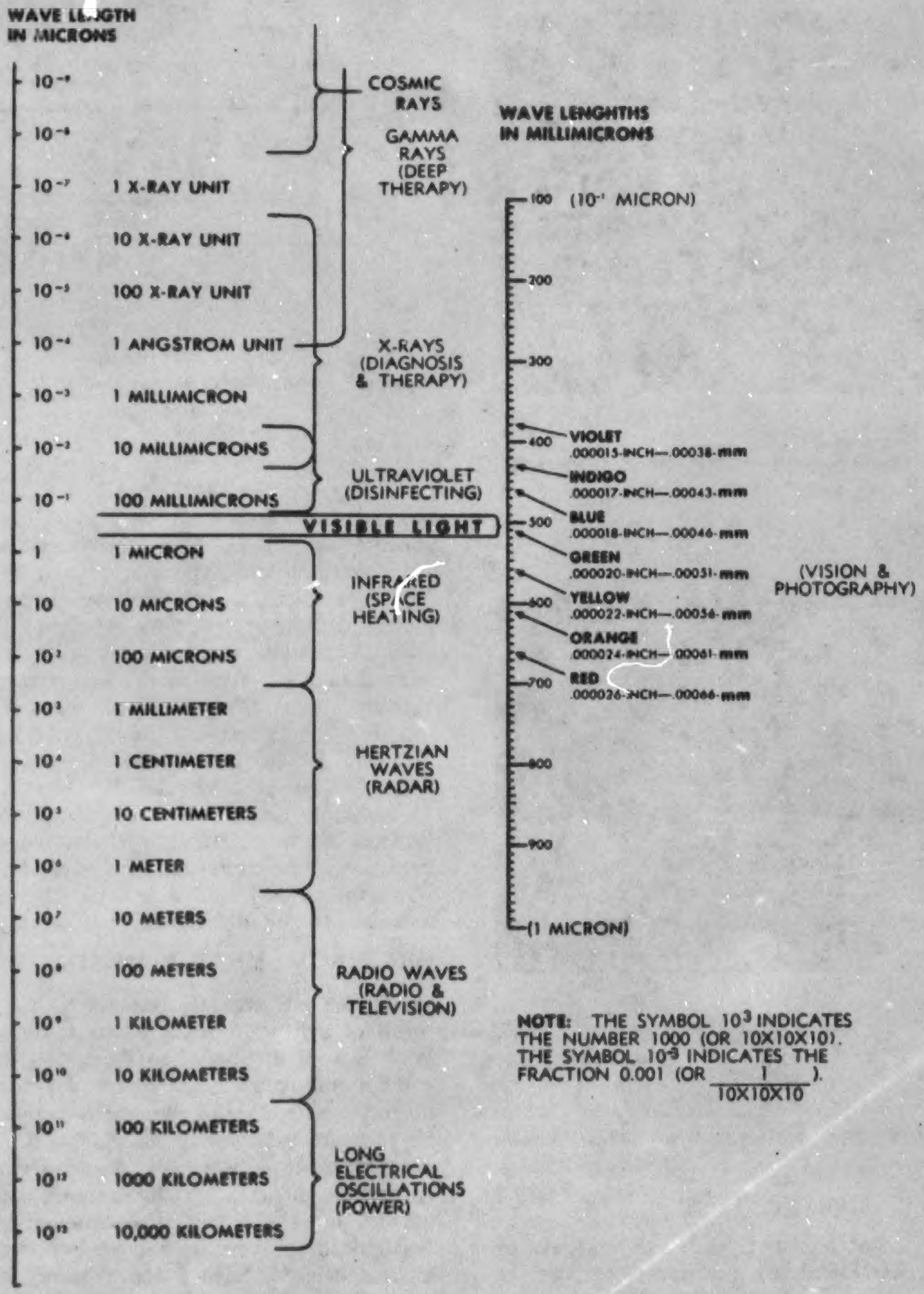
During World War II, SNOOPERSCOPES with powerful spotlights, which sent forth beams of invisible infrared light, were used to watch the enemy at night. When the infrared beams sent out by the spotlight struck an object and reflected it back to the snooperscope, the scope changed the infrared to visible wavelengths. SNIPERSCOPES used on rifles in the Pacific during the war work on the same principle as the snooperscope.

Observe in figure 2-10 that RADAR waves are adjacent to the infrared rays in the electromagnetic spectrum and have wavelength a little longer than infrared. We know that these wavelengths travel at the same speed as light because they have been sent to the moon and reflected back in about 2.6 seconds. Because the distance of the moon from the earth is approximately 240,000 miles (in round numbers), 2 X 240,000 ÷ 2.6 seconds = 184,615, the speed of radar in miles per second.

SPEED OF LIGHT

The difference in the speed of light through air, glass, and other substances accounts for the bending of light rays. Without this characteristic of light, a glass lens could not bend light rays to a focus, as you will learn later in this text. The length of all waves in the electromagnetic spectrum is also connected to corresponding frequencies and the speed of light.

Because light travels at such high velocity, it was years before anyone could measure its speed. Galileo tried to measure it by having two men in towers on hills some distance apart flash lights at each other. Each person flashed his light as soon as he saw the light signal of the other. Galileo thought he could determine the speed of light by dividing the total distance of light traveled by the time required for the transmission of signals. His experiment was not successful; he concluded that the speed of light was too great to be measured by this method. His final thought on the speed of light was that



NOTE: THE SYMBOL 10^3 INDICATES THE NUMBER 1000 (OR 10X10X10). THE SYMBOL 10^{-3} INDICATES THE FRACTION 0.001 (OR $\frac{1}{10X10X10}$).

137.18

Figure 2-10.—Electromagnetic spectrum.

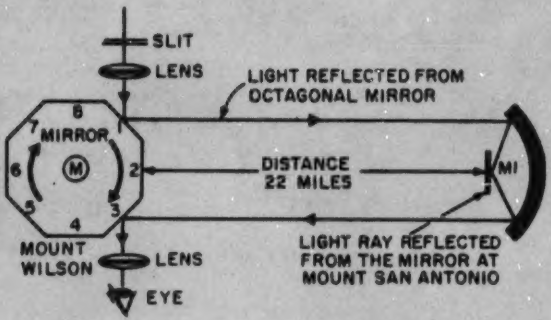
137.18
Figure 2-11.—Photograph of scene in illustration 2-12 taken by visible light.

137.17
Figure 2-12.—Photograph taken by infrared light.

its transmission through space was perhaps instantaneous.

ROEMER'S MEASUREMENT

In 1674 Olaus Roemer, a Danish astronomer, calculated the speed of light by observing the irregularities in the times between successive eclipses of the innermost moon of Jupiter by that planet.


SLIT
LENS
LIGHT REFLECTED FROM OCTAGONAL MIRROR
8
7
MIRROR
1
6
M
2
5
3
4
DISTANCE 22 MILES
MI
LIGHT RAY REFLECTED FROM THE MIRROR AT MOUNT SAN ANTONIO
MOUNT WILSON
LENS
EYE

137.13
Figure 2-13.—Michelson's mirror method for measuring the speed of light.

Roemer observed the position of Jupiter's moons revolving around the planet. The moons appeared on one side and then moved across in front of the planet and disappeared behind it. He could calculate accurately when one of the moons would be eclipsed by the planet. When he tried to calculate ahead six months, however, he learned that the moon eclipse occurred about 20 minutes later than he had calculated. He therefore concluded that the light had taken this amount of time to cross the diameter of the Earth's orbit, which is approximately 186,000,000 miles. The difficulty was that Roemer did not correctly evaluate the speed of light; later measurements showed that the time was about 1,000 seconds, which gave 186,000 miles per second as the velocity of light.

MICHELSON'S MEASUREMENTS

The most accurate measurements of the speed of light were made about 1926 by A. A. Michelson, a distinguished American physicist, and his colleagues. Michelson used an octagonal mirror in an apparatus illustrated in figure 2-13. He measured the speed of light in air over the exact distance between Mt. Wilson and Mt. San Antonio, California. The light source, octagonal mirror, and the telescope were located on Mt. Wilson and the concave and plane mirrors were located on Mt. San Antonio about 22 miles distant.

Study the illustration. Mirror (M) is stationary. Michelson passed a pencil of light through a slit and a lens to the octagonal mirror at 1. (NOTE: A pencil of light is a narrow group of light rays which come from a point source of light.) Mirror (M) then reflected the light to the concave mirror and mirror M^1 which reflects the pencil of light back to point 3 on the octagonal mirror (M). The octagonal mirror was next put into motion and increased in speed enough to move position 2 on the octagonal mirror into the position formerly occupied by position 3 during the time required for the light to travel from position 1 on the octagonal mirror to Mt. San Antonio and return. After several years of observation with his apparatus, Michelson concluded that the speed of light in air is 299,700 kilometers (a kilometer is .6214 mile) per second.

Sometime later, Michelson used an evacuated tube 1 mile long to measure the speed of light in a VACUUM. The vacuum tube removed variations in air density and haze from the test, and the experiment showed that the speed of light in a vacuum was slightly higher than in air. The velocity of light in a vacuum is generally accepted as 300,000 kilometers per second, or 186,000 miles per second.

Modern physicists compute the speed of light with great accuracy. Some of their measurements are based on light interference. For all practical purposes, however, the speed of light in air or in a vacuum is considered as 186,000 miles per second. In media more dense than air, the speed of light is slower, as indicated by the speed at which yellow light passes through the following substances:

Quartz	110,000 miles per second
Ordinary crown glass	122,691 miles per second
Rock salt	110,000 miles per second
Boro-silicate crown glass	122,047 miles per second
Carbon disulfide	114,000 miles per second
Medium flint glass	114,320 miles per second
Ethyl alcohol	137,000 miles per second
Water	140,000 miles per second
Diamond	77,000 miles per second

NOTE: All colors of light travel at the same speed in both air and empty space. In more dense media, the velocity of light varies for different colors depending on the wavelengths.

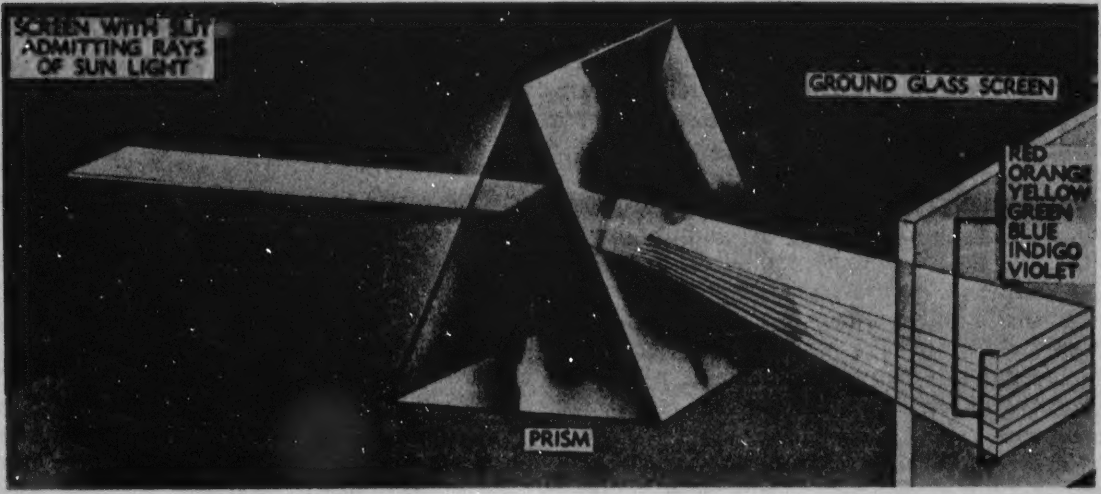
COLOR OF LIGHT

Because sunlight includes the whole range of wavelengths between 400 mμ and 700 mμ, it is a mixture of all visible colors between red and violet. Figure 2-14 shows how you can prove this. When the sun is shining, put a prism on a table in a room with one window. Cover the window with dark paper or cloth. Then cut a horizontal slit about 1 inch long and 1/16 inch wide in the paper to admit a small quantity of light. Hold the prism close to the slit to ensure passage of sunlight onto one of the long faces of the prism. (Lenses and prisms are discussed in detail in chapters 3 and 4.) At the same time, hold a ground glass screen or a sheet of white paper on the other side of the prism, 6 to 8 inches away. When the sunlight passes through the prism, wavelengths of various colors will refract at different angles toward the base of the prism and produce the colors of sunlight (the rainbow) on the glass screen or sheet of white paper. This breaking up of white light into its component colors is called DISPERSION. Notice that the red light, with a longer wavelength, is bent less than the violet which has a short wavelength.

SELECTIVE REFLECTION AND ABSORPTION

If you look at a piece of red paper in the sunlight, you see red; but this does not mean that the paper is making red light. What it does mean is that the paper is reflecting a high percentage of the red light which falls on it and is absorbing a high percentage of all other colors.

When you look through yellow glass, you see yellow because the glass is transmitting yellow light and is absorbing most of the other colors. Usually, yellow glass absorbs violet, blue, and some green, but it transmits yellow, orange, and red. When yellow, orange, red, and a little green all enter your eye at the same time, however, the color you see is yellow.



137.19

Figure 2-14.—Dispersion of light into a spectrum by a prism.

Selective absorption of light is what takes place when a color filter is used on an optical instrument. An image may be blurred by haze or fog, but when a yellow filter is put into the line of sight the image becomes sharper. The reason for this is that a thin haze permits most of the light to pass through; but it scatters some of the blue and violet light in all directions. Haze is therefore visible because of the scattered blue and violet colors. The yellow filter absorbs blue and violet and the haze becomes almost invisible. Filters made in any particular color will transmit light of longer wavelength than the color of the filter, but will absorb light of shorter wavelengths.

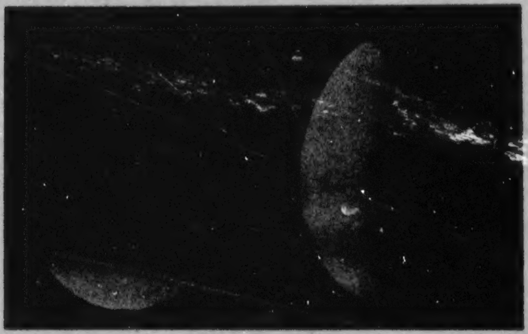
COLOR VISION

A pure spectral color is composed of light of one wavelength, or a very narrow band of wavelengths. When this light enters your eyes, it gives a sensation of color; but you cannot judge the wavelength of light from color sensation. Most of the colors you see are not pure spectral colors but mixtures of these colors. The sensation you get from these mixtures is therefore not always what you may expect.

VISIBILITY OF OBJECTS

To fully understand the ability to see an object, you must understand what light is and how it reacts with matter. To be sure you understand, review the 15 items listed below which you have studied:

1. Light is a form of energy.
2. Experiments show that light has the nature of particles and is dispersed in waves.
3. Luminous objects are a source of light.
4. Nonluminous objects reflect light from another source.
5. Visible objects reflect light that enters our eyes.
6. Light travels in straight lines as rays of light.
7. Only the energy of a wave travels.
8. The intensity of light is measured in candlepower (or lumens).
9. Wavelength is the distance between two successive waves.
10. Frequency is the number of waves passing a fixed point in 1 second.
11. Visible light is a relatively small range of the electromagnetic spectrum.



137.24

Figure 2-15.–Visual determination of difference between objects.

12. The speed of all electromagnetic waves is the same, even in a vacuum.

13. The speed in more dense media is less and varies with the wavelength.

14. White light is made up of a mixture of wavelengths between about 400 and 700 mμ.

15. When an object reflects some of the wavelengths of light, but absorbs others, it gives a sensation of color.

We see things because of reflected light. Objects look differently because they reflect light in a different manner. The difference in the intensity of light or the texture of a surface makes a difference in the visibility of an object. Color, likewise, makes a difference in the visibility of objects. If one object absorbs twice as much color as another object, you have no difficulty in differentiating between them. You can therefore judge the size and shape of an object because of the difference in color or intensity of reflected light.

Refer now to figure 2-15, one part of which is an egg and the other part a piece of white cardboard cut to the approximate dimensions of the egg. You can easily distinguish between them by the way light is reflected from them. All parts of the cardboard reflect light equally, because all rays of light fall on it at the same angle. Rays of light on the egg, however, strike the shell at different angles; the amount of light reflected from any surface depends upon the angle of incidence (explained later) at which the rays of light strike the shell.

Another way to tell the difference between the egg and the piece of cardboard is by the shadows cast by the egg. Observe the right side of the egg. Because of the difference in the angles at which the light strikes the egg, you can detect roughness in the shell. This roughness indicates texture, which causes an object to show minute differences in color or shape all over the surface.

For the sake of convenience, we can divide objects into three classes, according to the reaction of light when it falls upon them: opaque, translucent, and transparent.

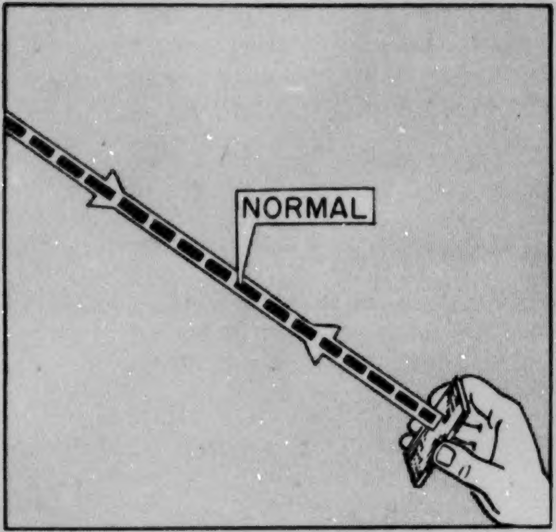
OPAQUE

All the light which falls upon an opaque object is either reflected or absorbed–none of the light passes through. This is important, because most objects are opaque. No object, however, is completely opaque. If it is thin enough, you can see through anything. Even heavy metals such as silver and gold allow some light to pass through them when they are painted in a thin film on glass.

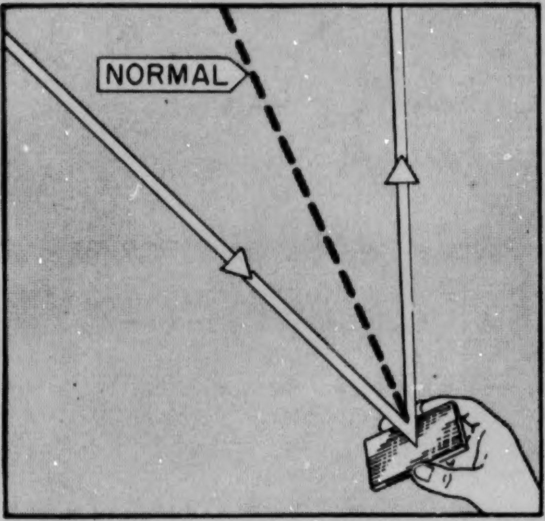
Tubes that hold lenses and prisms in optical systems are opaque to prevent entrance of light into the system except through the front lens. These tubes are painted a dull or flat-black color inside so that they will absorb and not reflect light which falls upon them.

TRANSLUCENT

When light falls upon a translucent object, some of it is absorbed and reflected, but most of the light passes through the object and diffuses or scatters in all directions. This is what happens, for example, when light passes through ground glass plate, stained glass windows, or a thin sheet of paper. If you hold these items in front of a strong light, you can see that much of the light passes through even though you are unable to see a clear image of the source of light.



137.25
Figure 2-16.—Reflection of a beam of light back on its normal or perpendicular.



137.26
Figure 2-17.—Reflection of beams of light at different angles.

TRANSPARENT

A transparent object reflects and absorbs a small amount of the light which strikes it, but permits most of the rays to pass through.

Reflection and absorption are prime factors in determining the quality of optical glass used in the manufacture of instruments. This will be discussed in greater detail later in the manual.

A window pane is a good example of a transparent object. Clear glass is considered to be transparent, but the thicker the glass, the greater its loss of transparency.

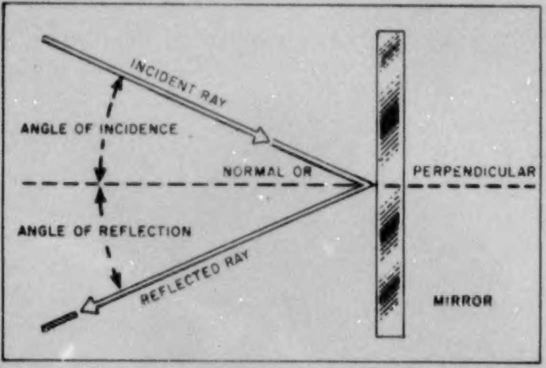
REFLECTION

You know from experience that a mirror reflects light. If you experiment with a plane mirror in a dark room with a window through which you can admit light, you will find that you can reflect a beam of light to almost any spot in the room. When you hold a mirror perpendicular to a beam of light, you can reflect the beam back along the same path by which it entered the room, as shown in figure 2-16.

If you shift the mirror to an angle from its perpendicular position, the reflected beam is shifted at an angle from the incoming beam twice as great as the angle by which you shifted the mirror. Study figure 2-17. If you hold the mirror at a 45° angle to the incoming beam, the reflected beam is projected at an angle of 90° to the incoming beam. Remember this characteristic of light.

The simple experiments just discussed illustrate one of the dependable actions of light. You can reflect light precisely to the point where you want it, because any kind of light reflected from a smooth, polished surface acts in the same manner. This property of light is used in many types of fire control instruments.

Refer now to figure 2-18. The ray of light which strikes the mirror is called the INCIDENT RAY, and the ray which bounces off the mirror is known as the REFLECTED RAY. The imaginary line perpendicular to the mirror at the point where the ray strikes is called the NORMAL or PERPENDICULAR. The angle between the incident ray and the normal is the ANGLE OF INCIDENCE: the angle between the reflected ray and the normal is the ANGLE OF REFLECTION.



110.30
Figure 2-18.–Terms used for explaining reflected light.

LAW OF REFLECTION

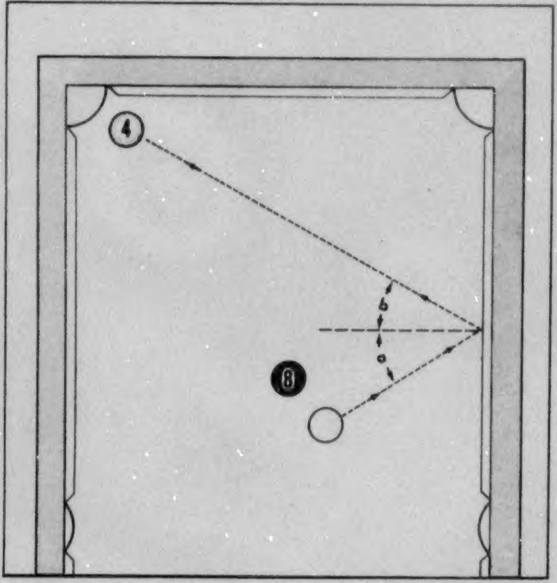
The law of reflection is covered by three basic statements:

1. The angle of reflection equals the angle of incidence.
2. The incident ray and the reflected ray lie on opposite sides of the normal.
3. The incident ray, the reflected ray, and the normal all lie in the same plane.

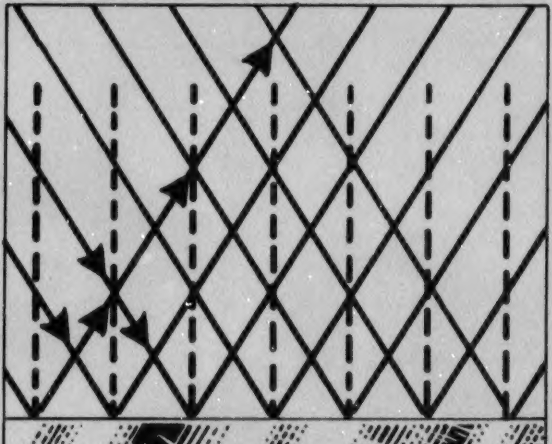
By applying the law of reflection, you can see that in all cases of reflection the angle of reflection can be plotted if the angle of incidence is known, or vice versa. To illustrate, study figure 2-19. In this instance you desire to put the No. 4 ball in the nearest pocket, but your cue ball is behind the 8 ball. If you are an expert pool player, you know where to strike the right side of the pool table with the cue ball in order to have it reflect on a line which will enable it to hit the No. 4 ball and put it in the pocket. Angle b must equal angle a.

REGULAR REFLECTION

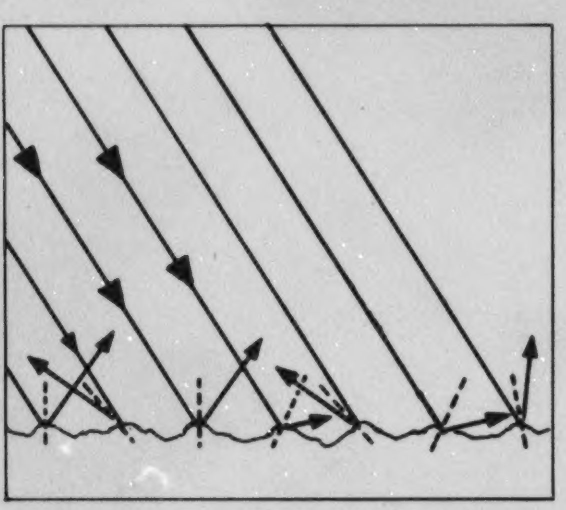
Mirrorlike reflection in which the angle of reflection is equal to the angle of incidence is called specular reflection which is commonly known as regular reflection. Specular reflection can come only from a plano polished surface, and, if the incident light is parallel, the reflected light will be parallel as shown in figure 2-20.



137.29
Figure 2-19.–Application of the law of reflection on a pool table.


DOTTED LINES—NORMAL

137.30
Figure 2-20.–Regular reflection.



137.31

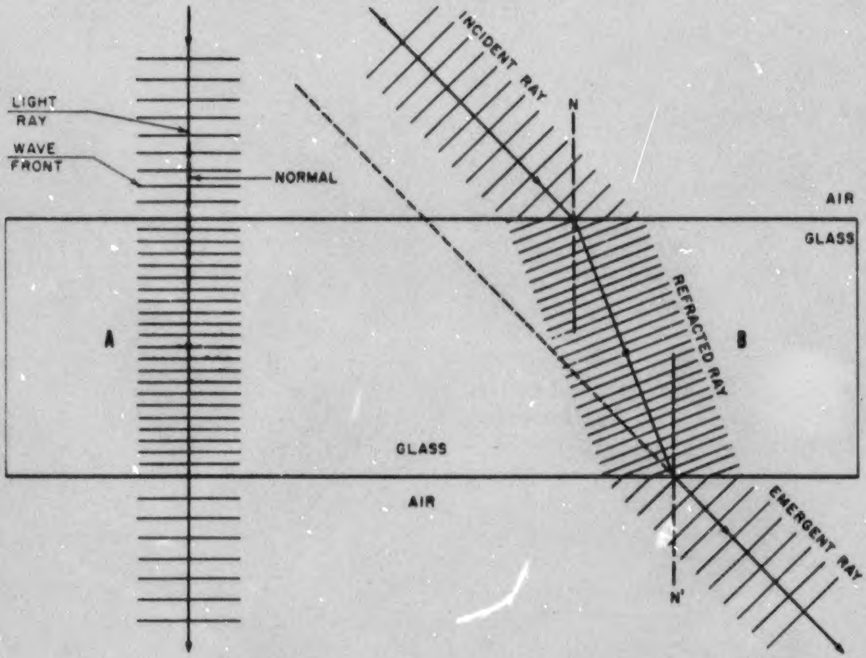
Figure 2-21.—Diffuse reflection.

DIFFUSE REFLECTION

The opposite of specular reflection is diffuse reflection, and it will occur when light is reflected from a rough surface. Diffuse reflection is defined as a random distribution of included angles for a series of rays traveling from the same source. As shown in figure 2-21, diffuse reflection is a scattering of the reflected light and it accounts for our ability to see all nonluminous objects as well as to distinguish shape and texture. The surface of the paper in this manual is essentially rough and the light that is reflected from it is diffused.

REFRACTION

As you study the meaning of refraction, refer to figure 2-22 which shows what happens to rays of light as they pass through a sheet of glass. Both plane surfaces of this glass plate are



137.32

Figure 2-22.—Refraction of light beams by a sheet of glass.

parallel, and air contacts both surfaces. Glass and air are transparent, but the glass is optically more dense than air; therefore, light travels approximately one-third slower in glass than in air.

Observe the dotted lines (N & N′) in the illustration. These are the normals erected for the incident and refracted rays. When a light ray (wave front) strikes the surface of the glass at right angles (parallel to the normal), it is not bent as it passes through the glass. This is true because each wave front strikes the surface squarely. The wave front is slowed down when it strikes the surface of the glass, but it continues in the same direction it was going before striking the glass. When it squarely strikes the other surface of the glass, it passes straight through without deviation from its course and resumes its original speed.

If a wave front strikes the first surface of the glass at an angle, as illustrated in part B of figure 2-22, the leading edge of the first wave front arrives at the surface an instant before the other edge; the leading edge is slowed down as it enters the more dense medium before the second edge enters. Observe that the second edge also continues to travel at the same speed until it strikes the surface of the glass. This slowing down of one edge of the wave front before the other edge slows down causes the front to pivot toward the normal.

The information just given about the way a wave front strikes a glass plate applies to ANY FREELY MOVING OBJECT. When one side of an object is slowed down as it hits something, the other side continues to move at the same speed and direction until it also hits something. This action causes the object to pivot in the direction of the side which hits first and to slow down. Unlike light, which is a form of energy, freely moving objects do not resume their original speed without the application of power of some sort. Pivoting or bending of light rays (wave fronts) as just explained, is called REFRACTION; and the bent (pivoted) rays are called REFRACTED RAYS.

If the optical density of a medium (glass in this case) remains constant, the refracted light rays continue to travel in a straight line, as shown in part B of figure 2-22, until the surface from which they emerge (glass-to-air surface) causes interference. At this point, an opposite effect occurs to a wave front. As the leading edge of the front reaches the surface (glass-to-air), it leaves the surface and resumes original speed (186,000 miles per second, at which it entered the glass).

Speeding up of one edge of a wave front before the other edge speeds up causes the front to pivot again; but this time it pivots toward the edge of the front which has not yet reached the surface of the glass. Again, this bending or pivoting of the wave front is called REFRACTION.

If the glass plate has parallel surfaces, the emergent light ray (ray refracted out of the glass) emerges from the second surface at an angle equal to the angle formed by the incident ray as it entered the glass. If you draw a dotted line along the emergent light ray (fig. 2-22) straight back to the apparent source of the ray, you will find that the emergent ray is parallel to the incident ray.

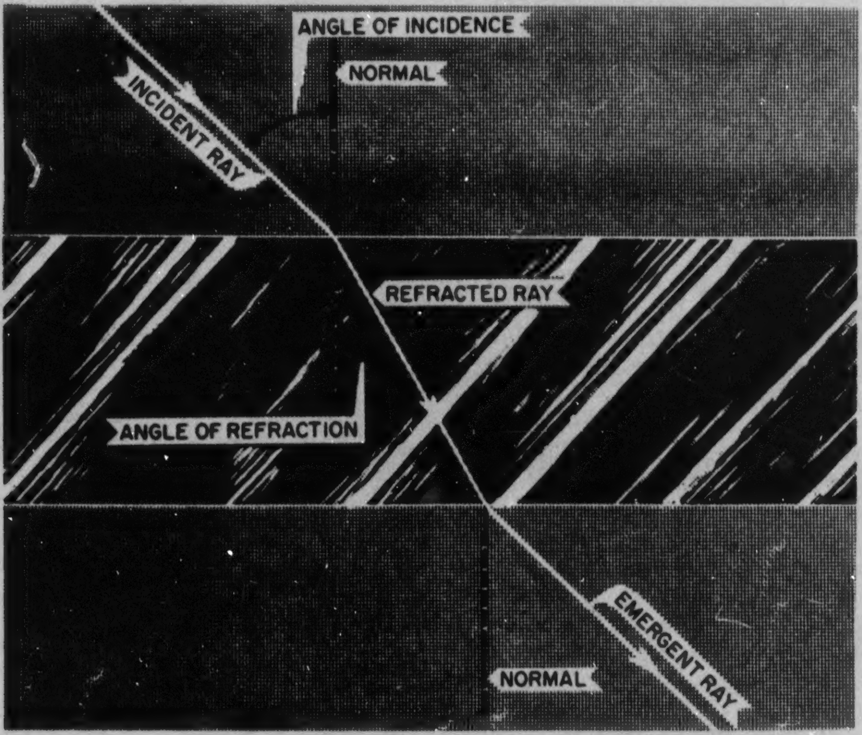
If the optical density of a medium entered by a light ray (wave front) is constant, the light follows its course in a direct line, as illustrated in part B of illustration 2-22.

LAWS OF REFRACTION

You should understand thoroughly all laws of refraction. Briefly stated, they are as follows:

1. When light travels from a medium of lesser density to a medium of greater density, the path of the light is bent toward the normal.
2. When light travels from a medium of greater density to a medium of lesser density, the path of the light is bent away from the normal.
3. The incident ray, the normal, and the refracted ray all lie in the same plane.
4. The incident ray lies on the opposite side of the normal from the refracted ray.

Study illustration 2-23 and then review carefully all laws of refraction. Note the normal, the angle of incidence, and the angle of refraction.

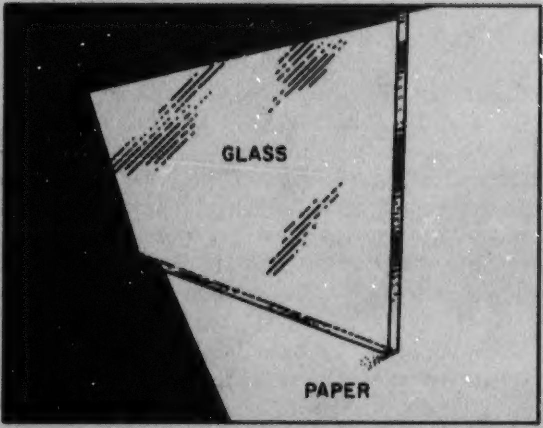


12.233

Figure 2-23.—Terms used for describing refraction.

The amount of refraction is dependent upon the angle at which light strikes a medium and the density of the new medium—the greater the angle of incidence and the more dense the new medium, the greater the angle of refraction. If the faces of the medium are parallel, the bending of light at the two faces is always the same. As illustrated in figure 2-23, the beam which leaves the optically more dense medium is parallel to the incident beam. An important thing to keep in mind in this respect, however, is that the emergent beam must emerge from the more dense medium into a medium of the same index of refraction as the one in which it was originally traveling: that is, air to glass to air, NOT air to glass to water (as an example).

You can visually demonstrate refraction by placing the straight edge of a sheet of paper at an angle under the edges of a glass plate held vertically (fig. 2-24). Observe that the straight



137.34

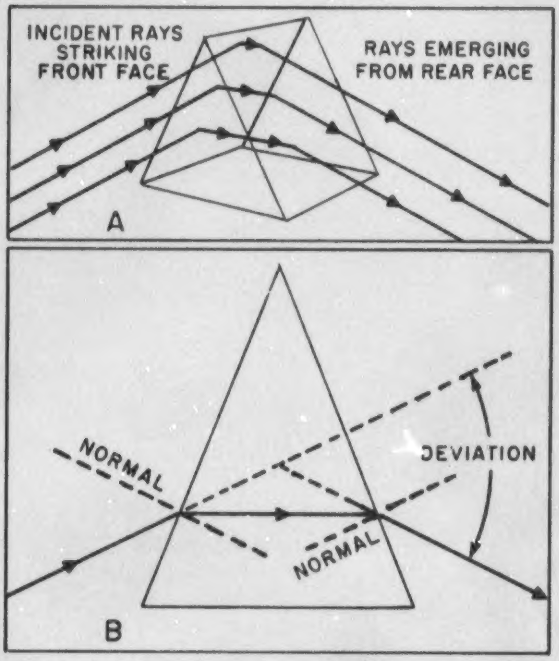
Figure 2-24.—Effects of refraction.

edge of the sheet of paper appears to have a jog in it directly under the edge of the glass plate. The portion of the paper on the other side of the glass appears displaced as a result of refraction. If you move the sheet of paper and change the angle of its straight edge, the amount of refraction is increased.

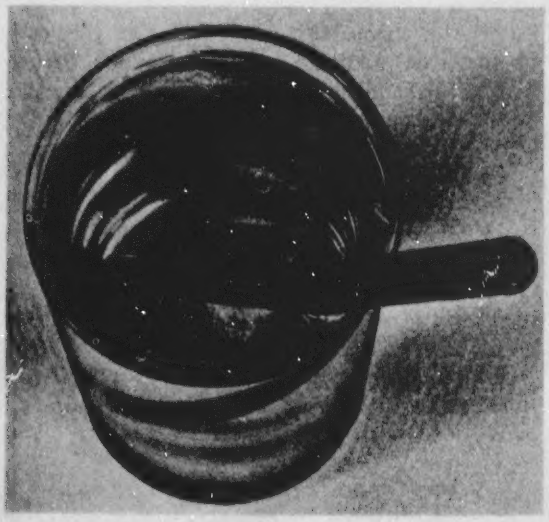
Study figure 2-25, which shows a straight stick in a glass of water. Note that the stick appears bent at the surface of the water. What you see is an optical illusion created by refraction. When a ray of light passes from air into water, it bends; and when it passes from the water into the air, it also bends. This illustration shows why a fish in water is not where it seems to be; it is much deeper.

Now observe figure 2-26. This illustration shows how light is affected by a medium whose entrance and emergence faces are not parallel to each other. As shown in the illustration, all laws of refraction still apply.

The angle between the refracted ray of light and a straight extension of the incident ray of light through the medium is called THE ANGLE OF DEVIATION. This is the angle through which the refracted ray is bent from its original path by the optical density of the refracting medium and the angle between the entrance and emergent faces.


INCIDENT RAYS STRIKING FRONT FACE
RAYS EMERGING FROM REAR FACE
A
NORMAL
DEVIATION
NORMAL
B

110.32
Figure 2-26.—Passage of light rays through a prism.



137.33
Figure 2-25.—Optical illusion caused by refraction.

INDEX OF REFRACTION

As you read earlier in this chapter, the speed of light in a vacuum is about 186,000 miles per second. Its speed through ordinary glass, however, is about 120,000 miles per second. This ratio between the speed of light in a vacuum and the speed of light in a transparent medium is known as the INDEX OF REFRACTION for that medium. On optical drawings and in optical textbooks, the index of refraction is designated by the letter n. It is written as a number and applies to the relation between the speed of light in a vacuum compared with the speed of light in the medium under consideration.

The index between two media is called the RELATIVE INDEX while the index between a medium and a vacuum is called the ABSOLUTE

INDEX. The index of refraction expressed in tables is the absolute index, while in practice the relative index is figured. When working with optical drawings of instruments, the relative index must be figured because you will have light passing from one medium to another (air to glass, glass to glass, and gas to glass).

To determine the absolute index the formula is:

$$\text{Index of refraction} = \frac{\text{Velocity in Vacuum}}{\text{Velocity in Medium}}$$

Now apply the formula to figure the absolute index of a diamond in which light travels at 77,000 miles per second.

$$n = \frac{186{,}000}{77{,}000} = 2.415$$

If you need to determine the relative index of a diamond in water, you need only substitute the velocity in water for the velocity in a vacuum.

$$n = \frac{140{,}000}{77{,}000} = 1.818$$

Following is a list of absolute indices of refraction for some materials:

Vacuum	1.000
Air	1.0003
Water	1.33
Fused quartz	1.46
Crown glass	1.52
Canada balsam	1.53
Light flint glass	1.57

NOTE: For most computations the index of air is considered to be the same as vacuum (1.000).

Since the index of refraction of transparent materials of high purity shows a constant relationship to the physical properties of the materials, you can determine the identity of transparent materials by measuring their indices of refraction.

ANGLE OF REFRACTION

The amount that a ray of light is refracted (angle of refraction) in a transparent medium depends on two factors:

1. The angle at which light strikes the surface (angle of incidence)
2. The density of the medium (index of refraction)

When light from the same source strikes two different media at the same angle, the light striking the medium with the highest index of refraction is refracted the most.

In 1621, Willebrord Snell, a Dutch astronomer and mathematician at the University of Heyden, found the correct relation between the angle of incidence and the angle of refraction. Snell developed a formula for determining the angle of refraction known as SNELL'S LAW.

$$n \text{ sine } \theta = n' \text{ sine } \theta'$$

In this formula, n is the index of refraction in the first medium, n′ is the index for the second medium, sine is a trigonometric function, and θ (the Greek letter theta) refers to the first angle, while θ' refers to the second angle.

Simply stated, Snell's law says:

- The index of refraction of the first medium times the sine of the angle of incidence is equal to the index of refraction of the second medium times the sine of the angle of refraction.

NOTE: In order to find the sine of an angle, you must refer to a table of natural trigonometric functions.

A very important thing for the reader to remember is always measure the angle of incidence between the incident ray and the normal; likewise, measure the angle of refraction between the normal and the refracted ray.

In order to apply the formula to a practical problem let's assume that the ray of light in figure 2-23 is contacting, at an angle of 45°, a plate of glass whose index of refraction is 1.500. According to Snell's law, the index of refraction (n) of the first medium (air = 1.000) times the sine of the angle of incidence (45° = .7071) equals the index of refraction (n') of the second medium (glass = 1.500) times the sine of the angle of refraction.

$$1.000 \times .7071 = 1.500 \times \text{sine } \theta'$$

$$.7071 = 1.500 \times \text{sine } \theta'$$

$$\frac{.7071}{1.500} = \text{sine } \theta'$$

$$.4714 = \text{sine } \theta'$$

By referring once again to the natural trigonometric tables, you will find that .4714 is the value of the angle 28°7'30", the angle of refraction in the second medium.

If you now reverse the direction of the light ray to where the first medium is glass, the second medium is air, and the angle of incidence at the surface of the glass is 28°7'30", you will find the angle of refraction is 45°. This may seem strange, but by application of Snell's law the formula will be:

$$1.500 \times .4714 = 1.000 \times \text{sine } \theta'$$

$$.7071 = 1.000 \times \text{sine } \theta'$$

$$\frac{.7071}{1.000} = \text{sine } \theta'$$

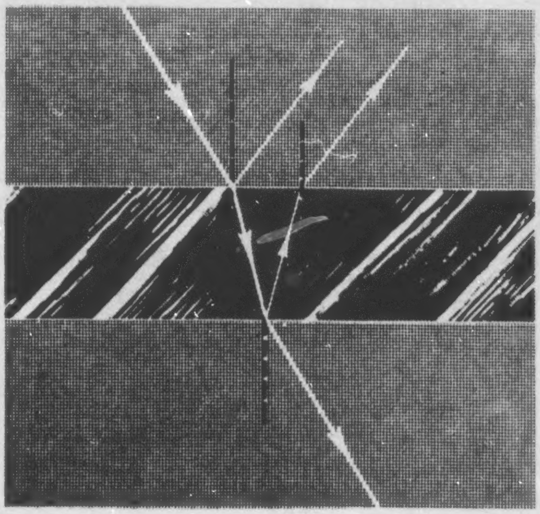
$$.7071 = 45^\circ$$

What you have just proved by solving the last equation is known as the LAW OF REVERSIBILITY, something you should remember. The law means that if the direction of a ray of light at any point in an optical system is reversed, the ray retraces its path back through the system, regardless of the number of prisms, mirrors, or lenses in the system.

REFLECTION AND REFRACTION COMBINED

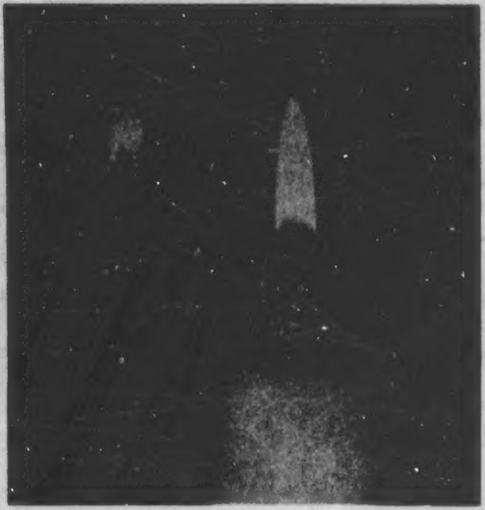
Smooth glass reflects about 4% of the light which falls upon it (more if the angle of incidence is large), but most of the light which enters the glass is refracted. Figure 2-27 shows a ray of light passing through plate glass. The dotted lines are the normals. The white (upward) arrow to the right of the first normal line indicates reflected light. The line of light which extends upward from the second normal represents the amount of light reflected back into the glass when the light strikes the lower surface. This is called INTERNAL REFLECTION. An internally reflected ray of light is refracted at the upper surface of the glass and emerges parallel to the reflection from the incident ray.

Study illustration 2-28, which shows reflections from both surfaces of a glass plate. Note the two images. If you have several plates of glass in a stack with thin layers of air between the plates, you can see twice as many reflections as the number of plates of glass. NOTE: You will occasionally find a condition such as this in optical instruments.



137.35

Figure 2-27.—Reflection and refraction combined.



137.36

Figure 2-28.—Reflection from the surfaces of a glass plate.

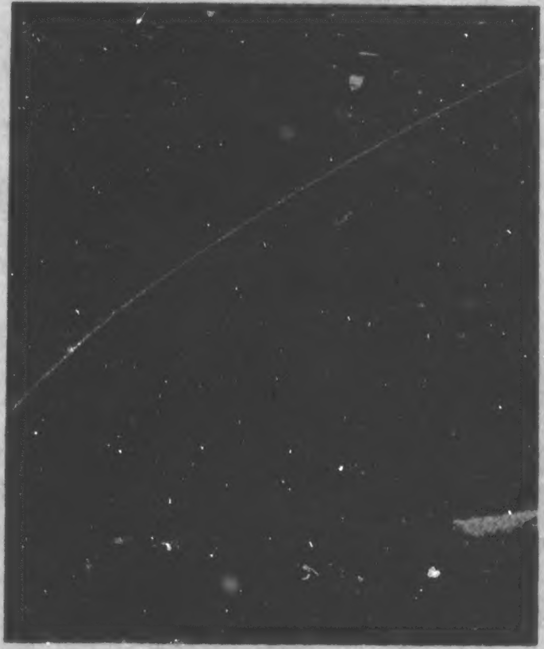
If there are 5 lenses in a system, there are 10 faces; and each face reflects part of the light. The image you see when you look through the instrument is formed only by the light which passes through all the lenses. A complex instrument such as a submarine periscope may have many surfaces which reflect part of the light, and the optical elements must have a film or coating applied to them to eliminate reflection and prevent loss of light in the instrument.

You know that optical glass is highly transparent, but it is still visible because of reflected light from its surface. Other glass objects are visible partly because of refraction. You can see part of the background through the glass, but the glass bends the rays from the background before they reach your eyes. In accordance with the angle at which it strikes the surface of the glass, each ray bends at a different angle. The background, therefore, appears distorted when you see it through the glass, as in figure 2-29. The glass rod, however, is clearly visible because of refraction caused by the shape of the rod and reflection of light from the surface of the rod.

Figure 2-30 is the same as figure 2-29 except that water has been put into the glass

137.37

Figure 2-29.—Visibility resulting from combined reflection and refraction.



137.38

Figure 2-30.—Effect of visibility by the reduction of reflection and refraction.

beaker, and the part of the glass rod in the water appears different from the part out of the water. The reason for this is that the index of refraction between the two media is now much smaller, so there is less reflection but a larger amount of refraction due to the curved surface of the water in the beaker. This curved surface causes a varied amount of refraction so the rod in the water appears larger.

If the water in the beaker is replaced with a solution having the same index of refraction as the glass, there will be no reflection or refraction taking place between the surface of the rod and the solution. See figure 2-31.

Reflection can take place ONLY at a surface between two media with different indices of refraction. Because the rod in figure 2-29 is in the air, the difference between the two media is fairly large and the rod is visible. This same rule applies to refraction, as you can prove by Snell's law. If the indices of refraction of the two media are identical, the angle of incidence equals the angle of refraction and there is NO refraction.

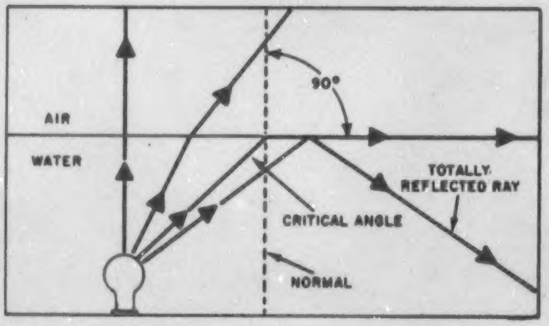
137.39
Figure 2-31.–Elimination of visibility by eliminating reflection and refraction.

TOTAL INTERNAL REFLECTION

You have learned that a small amount of reflection occurs when light passes from one transparent medium to another as in figure 2-27. When light passes from a more dense medium to a less dense medium there is one special angle of incidence which will not produce refraction nor reflection as we have thus far studied. This special angle of incidence is called the CRITICAL ANGLE and, when an incident ray strikes the surface between the two media at this angle, it will be transmitted along the media's surface as shown in figure 2-32.

Should a ray of light strike the surface at an angle of incidence greater than the critical angle, total internal reflection will occur (fig. 2-32). This phenomena of total internal reflection is very useful and will be discussed further with prisms in chapter 3.

Study figure 2-32 carefully. This shows that rays of light from an underwater source are incident at various angles to the surface. You will notice that as the angle of incidence increases, the angle of refraction becomes proportionately greater, until you reach the critical angle. When you reach the critical angle and the ray is refracted along the surface, the angle of refraction is 90° to the normal. Always bear in mind that the critical angle can only be shown when light is traveling from a more dense to a less dense medium. Remember that for all



137.40
Figure 2-32.–Angles of light rays from an underwater source.

angles of incidence greater than the critical angle, total reflection will result.

The actual critical angle of an optical medium depends upon the index of refraction of that medium. The higher the index of refraction, the smaller the critical angle.

Suppose you want to calculate the critical angle of a medium when the other medium is air. How can you do this? Use water as one medium, as an example, and air as the other; then make proper substitutuions in the formula (Snell's law) and solve the equation. The index of refraction of water is 1.333; when the angle of incidence is the critical angle, the angle of refraction is 90°. The procedure for solving the problem follows:

$$n \text{ sine } \theta = n' \text{ sine } \theta$$

$$1.333 \text{ sine } \theta = 1.000 \text{ sine } 90^\circ$$

(The sine of 90° is 1.000)

$$1.333 \text{ sine } \theta = 1.000 \times 1.000$$

$$\text{sine } \theta = \frac{1.000}{1.333} = .75018$$

$$\theta = 48^\circ 36'$$

Critical angles for various substances (when the external medium is air) are as follows:

Water	48°36′
Crown glass	41°18′
Quartz	40°22′
Flint glass	37°34′
Diamond	24°26′

The small critical angle of a diamond accounts for its brillance, provided it is a well cut diamond. The brilliance is due to total internal reflection of light; the light is reflected back and forth many times before it emerges to produce bright, multiple reflections.

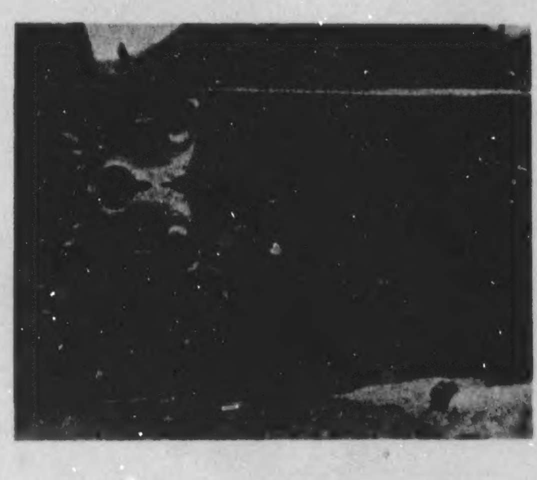
One example of total internal reflection at the surface of water is shown in figure 2-33. Rays of light from the fish strike the upper surface of the water at an angle greater than the critical angle and are reflected downward into the water. The reflected rays, however, strike the end of the aquarium at less than the critical angle, so they pass through and you can see an image of the fish reflected by the upper surface of the water. The path of a reflected ray is illustrated in figure 2-34.

ATMOSPHERIC REFRACTION

At a surface which separates two media of different indices of refraction, the direction of the path of light changes abruptly when it passes through the surface. If the index of refraction of a single medium changes gradually as the light proceeds from point to point, the path of light also changes gradually and is curved.

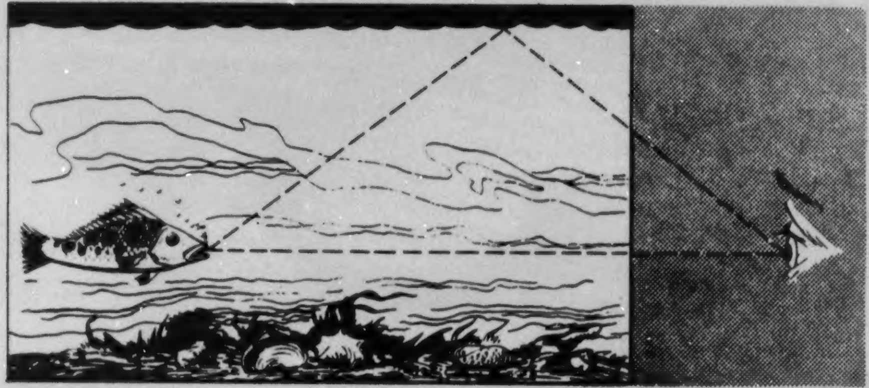
Although when air is most dense it has a refractive index of only 1.000292, the index is sufficient to bend light rays from the sun toward the earth when these rays strike the atmosphere at an angle.

The earth's atmosphere is a medium which becomes more dense toward the surface of the earth. As a result, a ray of light traveling through



137.41

Figure 2-33.—Total internal reflection at the surface of water.



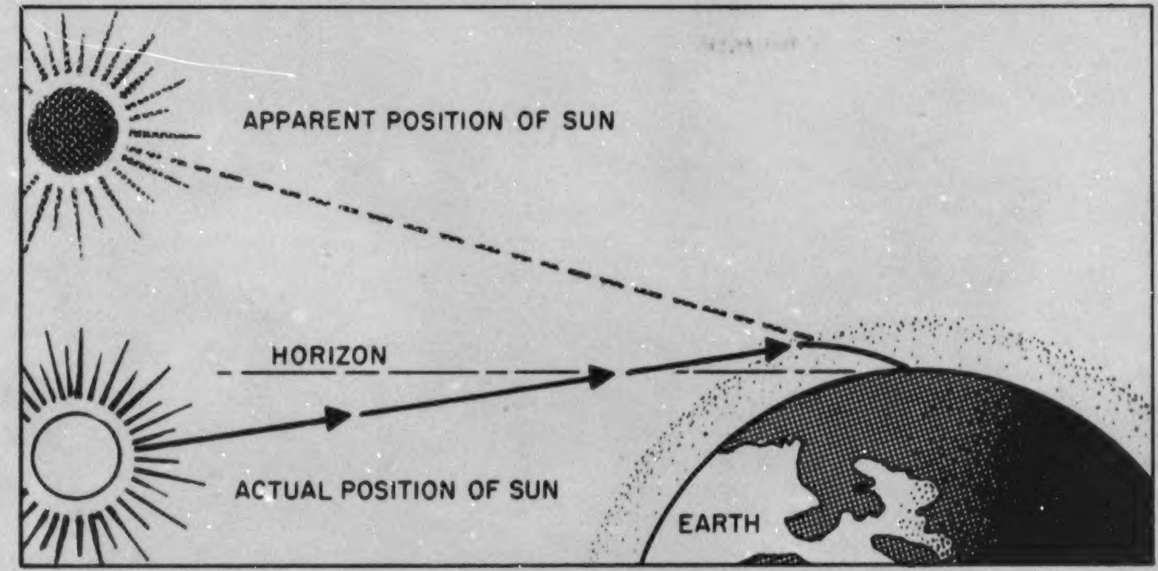
137.42

Figure 2-34.—Effect of total internal reflection on light rays.

the atmosphere toward the earth at an angle does not travel in a straight line but is refracted and follows a curved path. From points near the horizon, in fact, the bending of light is so great that the setting sun is visible even after it is below the horizon (fig. 2-35).

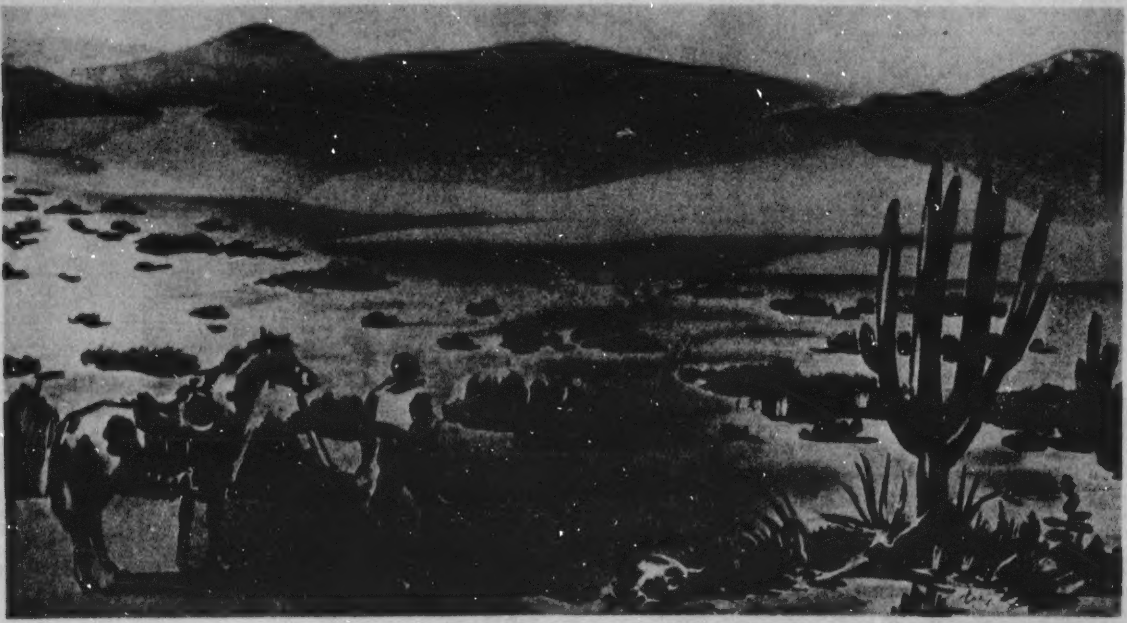
Mirages

Over large areas of heated sand or water there are layers of air which differ greatly in temperature and refractive indices. Under such conditions, erect or inverted (sometimes much



137.44

Figure 2-35.—Visibility of the sun below the horizon as a result of refracted light.



137.45

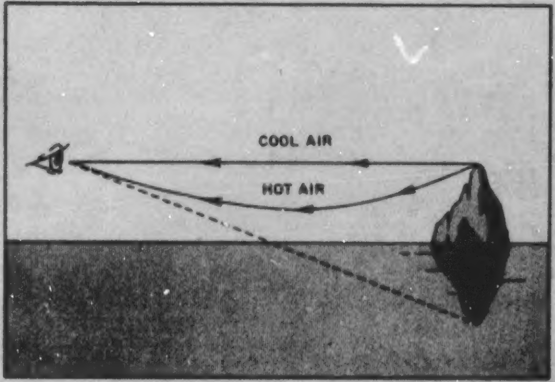
Figure 2-36.—Picture of a mirage in a desert.

distorted) images are formed which are visible from great distances. These images are MIRAGES.

Observe the apparent lake of water in a desert in illustration 2-36. This looks like a real lake but it is ONLY a mirage caused by the refraction of light over the hot sand. The sand heats the air directly above it, though the air at a higher level remains comparatively cool. Because cool air is more dense than hot air, the index of refraction is fairly low at the surface and gradually increases at higher and higher altitudes.

Study illustration 2-37 to learn what happens to light rays in a mirage. Light rays in cool air do not bend, as shown, but the ray which travels downward toward the hot air curves upward. When an observer looks at an object along the hot air ray, he thinks he sees it along the dotted line in the illustration.

You perhaps have observed mirages on asphalt highways on clear, hot days. When the highway rises in front of you and then flattens out, its surface forms a small angle with your line of sight, and you see reflections of the sky. These reflections look like puddles of water in the road. Under proper conditions of the



137.46

Figure 2-37.—Path of light rays in a mirage.

atmosphere and light, you can even see an approaching car reflected in the mirage.

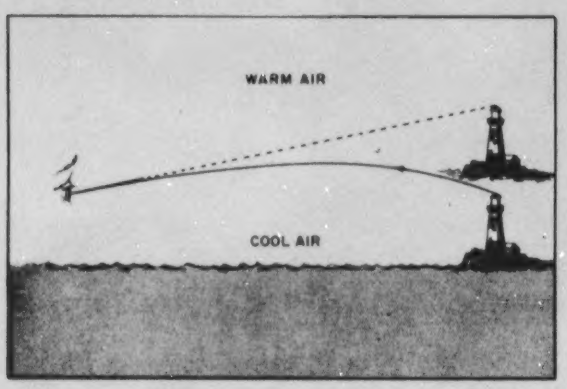
Looming

Looming is the exact opposite of a mirage. Ships, lighthouses, objects, and islands sometimes loom—they appear to hang in the sky above their real locations. On some bodies of water (Gulf of California and Chesapeake Bay, for example) looming is common. Figure 2-38 shows the path of light rays in looming.

The reason for looming is that air is cooled at the water's surface and index of refraction of the air decreases higher up causing the rays of light to bend downward, as shown in the illustration. This explains why a lighthouse sometimes appears to hang in the sky.

Heat Waves

On a hot day the columns of heated air which rise from the earth are optically different from the surrounding air and rays of light are irregularly refracted. The air is turbulent, and conditions under which observations are made change constantly. An object viewed through such layers of air therefore appears to be in motion and the air is boiling, or the image is dancing because of heat waves. This condition is particularly bad for using a high-powered telescope of more than 20 power. The heat waves are caused by the refraction of light waves at various angles, thereby creating a distortion.



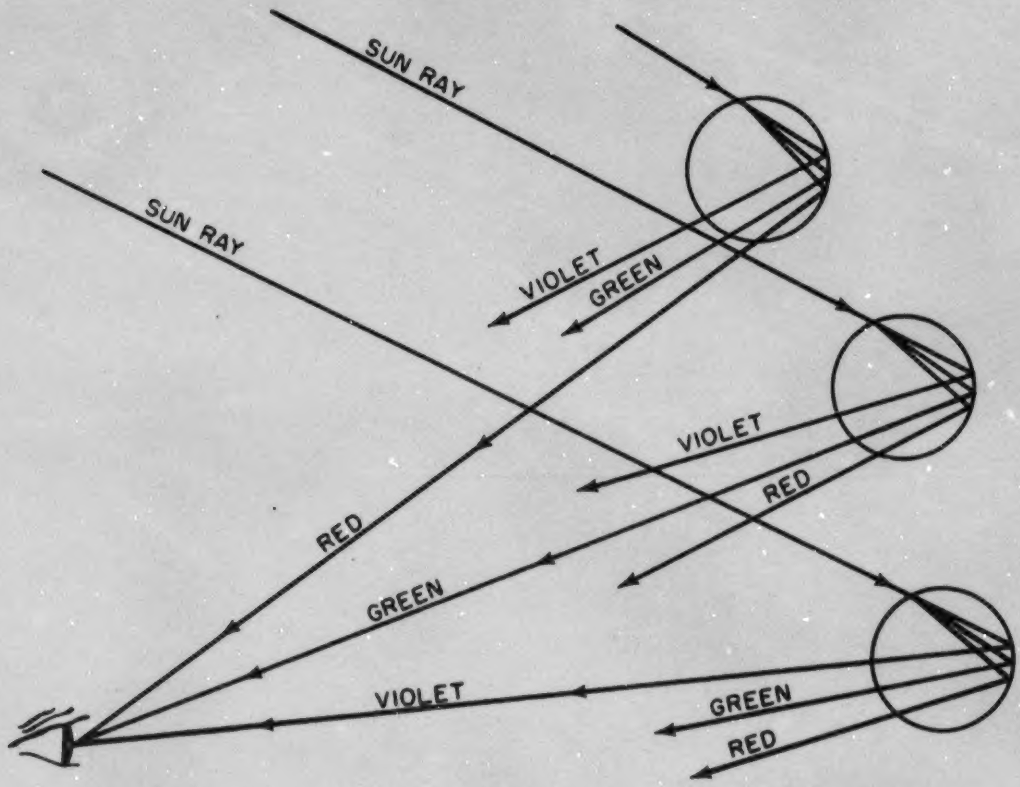
137.47

Figure 2-38.—Path of light rays from a looming object.

Rainbows

The formation of a rainbow is a good example of refraction, reflection, and dispersion all combined. Before you can see a rainbow, however, several conditions must be ideal. First of all, you must be looking toward a point where the atmosphere holds millions of drops of water, either in the form of mist or falling rain. The sun must be shining from a point behind you and it must be fairly low in the sky. (When standing on the ground, you can rarely see a natural rainbow at noon).

Figure 2-39 illustrates what takes place in the formation of a rainbow. Of course, it takes millions of drops of water and you see seven colors, but, for simplicity, the diagram only shows three drops of water and three colors. Rays of light are striking at many points on the surface of each drop, but the rays that strike at certain points, as shown in the diagram, are the only ones that can be seen. When the ray enters the drop of water, it is immediately refracted and dispersed. The light is then reflected back toward the surface due to internal reflection and is refracted again as it leaves the drop of water, continuing to be dispersed into spectral color as it enters the atmosphere again.



137.48

Figure 2-39.—Formation of a rainbow.

47

CHAPTER 3

MIRRORS AND PRISMS

This chapter is devoted primarily to descriptions of plane mirrors and prisms and the effect they have on light transmission. However, before you get into the discussion of mirrors and prisms, you should be familiar with two basic factors—measurement systems used in optics and image descriptions.

MEASUREMENTS IN OPTICS

An Opticalman at various times works with at least four systems of measurement: the English system, metric system, degree system, and mil system. You are already familiar with the English system where the basic unit, the foot, can be converted to smaller or larger units by multiplying or dividing by known conversion factors. The English system is not entirely satisfactory for optical measurements because it is complicated and cumbersome. The lack of simple relationships between units makes it very difficult to carry out computations. Hence, other systems of measurement are sometimes more desirable.

METRIC SYSTEM

Shortly after the French Revolution, near the end of the 18th century, the National Assembly of France decided to appoint a commission to develop a more logical measuring system than those in use at that time. The product of that commission was the "metric system," which has been adopted by most industrialized countries except the United States. The United States is beginning a slow conversion to the metric system.

In 1960, the International Conference on Weights and Measures adopted a modernized version of the metric system called the International System of Units, (SI). SI was established by international agreement to provide a logical interconnected framework for all measurements in science, industry, and commerce. The six base units of measure under SI are:

Length = meter (m)
Mass = kilogram (k)
Temperature = kelvin (K)
Time = second (s)
Electric current = ampere (A)
Luminous intensity = candela - cd

In your work as an Opticalman, you will use the metric system of measuring as well as the English system. The diameter and focal length of lenses are usually stated on optical drawings, for example, in millimeters—not in inches. In addition, with some experience, you will find the metric system much easier to use than the English system.

Decimals are basic in the metric system of measurement. You can easily convert from one unit to another. Suppose you know that an object is 0.67 meter long and you need to know the length in decimeters. All you need do is multiply by 10 to find that it is 6.7 decimeters in length. If you wish the length in centimeters, multiply by 100, and you get 67 cm. For the length in millimeters, multiply by 1,000 and you get 670 mm.

Suppose you are using the English system and need to convert the measurement of an object which is 0.67 yard long into feet. You must multiply by 3 to get the answer in feet and by 36 to get the answer in inches.

What, then, is the difference between using the English and metric system of measurement? The English system has several conversion factors, whereas, in the metric system, all you need do is move the decimal point.

The unit of length in the metric system is a meter which is equal to 39.37 inches. A meter is divided into 100 equal parts called centimeters; and each centimeter is divided into ten parts called millimeters because each millimeter is 1/1,000 part of a meter. All units of linear measurement of the metric system are multiples or fractional parts of a meter in units of 10.

Following is a table of metric units, with their equivalents in inches, yards, or miles:

		1 millimeter	=	.03937	inch
10 millimeters	=	1 centimeter	=	.3937	inch
10 centimeters	=	1 decimeter	=	3.937	inches
10 decimeters	=	1 meter	=	1.0936	yards
10 meters	=	1 dekameter	=	10.936	yards
10 dekameters	=	1 hectometer	=	109.36	yards
10 hectometers	=	1 kilometer	=	.6214	miles

The names of multiples in the metric system are formed by adding the Greek prefixes: deka (ten), hecto (hundred), kilo (thousand), and mega (million). Submultiples of the system are formed by adding Latin prefixes: deci (tenth), centi (hundredth), milli (thousandth), and micro (millionth).

For quick, approximate conversion from inches to the metric system units, or vice versa, refer to a metric unit-inch conversion table, which your optical shop will have. For more exact conversion, and for conversion of large units, use the following table:

From	To	Multiply	
Millimeters	Inches	Millimeters by	.03937
Inches	Millimeters	Inches by	25.4
Meters	Inches	Meters by	39.37
Meters	Yards	Meters by	1.0936
Inches	Meters	Inches by	.0254
Yards	Meters	Yards by	.9144
Kilometers	Miles	Kilometers by	.6214
Miles	Kilometers	Miles by	1.609

The unit of volume in the metric system is a LITER which is the volume of a cube 1/10th of a meter on each side. A liter is equal to 1,000 cubic centimeters which is equivalent to 1.057 quarts.

The unit of mass in the metric system is a GRAM which is the weight of 1 milliliter (ml) of distilled water at 4°C. For all practical purposes, a gram may be considered as the weight of 1 cubic centimeter of water.

The three standard units of the metric system (meter, liter, and gram) have decimal multiples and submultiples which make it easy to use for all purposes. Every unit of length, volume, or mass is exactly 1/10th the size of the next larger unit.

Standard abbreviations for principal metric units are:

Meter	m
Centimeter	cm
Millimeter	mm
Liter	l
Milliliter	ml
Cubic centimeter	cm^3
Gram	g
Kilogram	kg
Milligram	mg

DEGREE SYSTEM

The degree system is a means of measuring and designating angles or arcs. A degree is 1/360 of the circumference of a circle, or the value of the angle formed by dividing a right angle into 90 equal parts. Each degree is divided into 60 parts called minutes, and each minute is divided into 60 parts called seconds.

NAVY MIL

A Navy mil is a unit of measurement for angles, much smaller than a degree—1/6,400 of the circumference of a circle.

A mil is the value of the acute angle of a triangle whose height is 1,000 times its base. For example, when you look at an object 1,000 meters distant and 1 meter wide, the object intercepts a visual angle of 1 mil. Another way to say this is: A mil is an angle whose sine or tangent is 1/1,000. NOTE: For very small angles, the sine and tangent are practically the same.

IMAGE DESCRIPTION

An image is a representation or optical counterpart of an object produced by means of light rays. An image-forming optical element forms an image by collecting a bundle of light rays which diverge from an object point and transforming them into a bundle of rays which either converges or diverges from another point. If the beam actually converges to a point, a "real image" of the object is produced. If the beam diverges from a point, it produces a "virtual image" of the object.

REAL IMAGE

A real image is one that actually exists and is produced when the rays of light coming from an object converge at a common point. The image formed by the lens of a camera on the ground glass plate, as illustrated in figure 3-1, is the real image. A real image can be projected on a screen as with a movie projector.

137.49

Figure 3-1.—Real image of a sailor on photographic plate.

Refer now to figure 3-2 and trace the incident light rays from the object to the ground glass of the camera where the real image is formed. The plane in which the image lies is called the image plane—where all of the converging light rays intersect.

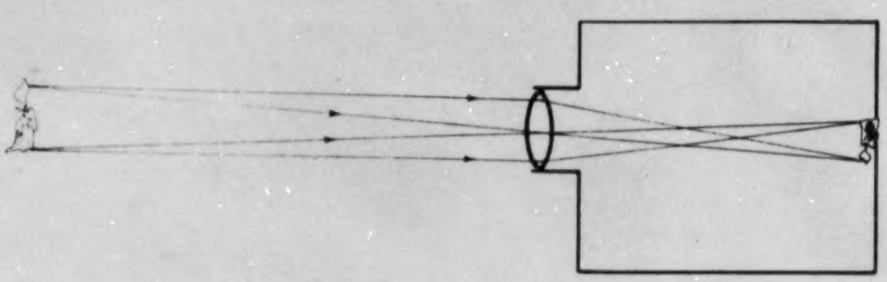
VIRTUAL IMAGE

A virtual image is so called because it does not have a real existence. It exists only in the mind and is apparent only to the eyes of the observer. A good example is the virtual image seen by the sailor in figure 3-3. The image of the sailor looking into the mirror appears to be on the other side of the mirror, a distance equal to the distance between the sailor and the mirror.

A virtual image exists only when it is viewed by the eye, in contrast with the real image that actually exists and can be reproduced by film or projected on a screen.

IMAGE ATTITUDE

One of the most import features a designer must consider when designing an optical system is "image attitude." In fact, the position of the image in relation to the object is often the primary reason for using an optical system. In



137.494

Figure 3-2.—Formation of a real image by a positive camera lens.

137.50

Figure 3-3.—Virtual image of a sailor as seen in a mirror.

describing image attitude, we use the terms invert and revert. Invert means to turn over, or upside down. Thus, for object R, the inverted image is ꓤ . Revert means to turn the opposite way so that right becomes left and vice versa. Thus, for object R, the reverted image is Я . An important point to remember when you describe any image, is to always compare the actual appearance of an object with the altered appearance produced by an optical element.

To describe an image, you can say that it is:

1. Real or virtual
2. Erect or inverted
3. Normal or reverted
4. Of the same size as the actual object or enlarged or diminished.

Normal and Erect

If the image has the identical attitude as the object, it is said to be normal and erect. This is illustrated by the letter F shown in figure 3-4A. The image could be larger or smaller than the actual object in this or the following three situations.

Reverted and Erect

When you look in a mirror, as the sailor in figure 3-3, you don't see yourself as others see you because your image is reverted. If you held a cut out of the letter F up to a mirror, it would be reverted and erect as illustrated in figure 3-4B.

Normal and Inverted

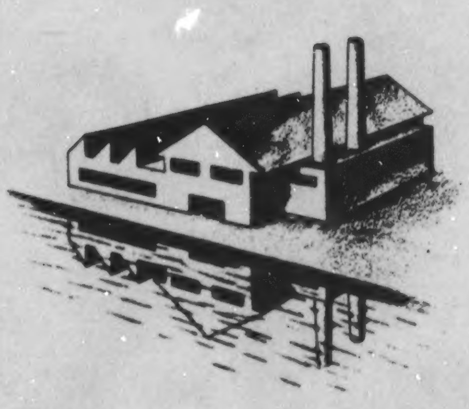
The image of an object that is upside down only is termed normal and inverted (fig. 3-4C). An example of how an image can be normal yet inverted is shown in figure 3-5, where you view a building reflected on the surface of water.

Reverted and Inverted

Refer again to illustration 3-1. The image of the sailor in this illustration is formed on a photographic plate (ground glass) by the lens of a camera. The image is inverted (upside-down) and reverted (left to right). You know this is

137.52

Figure 3-4.–Various image attitudes of the letter "F."



142.243

Figure 3-5.–Normal and inverted reflected image.

true because the sailor is the object, which is erect; and his picture on the ground glass is the image (upside-down). NOTE: ALWAYS COMPARE THE IMAGE WITH THE ACTUAL OBJECT.

The rule for describing an image, in comparison with the object which formed it, is as follows: Stand between the optical element and the object and look at the object. Then, stand so that you may view the image which is formed and compare the attitude of the image with the way the object looks.

Now study part A of figure 3-6 which shows you where to stand to view an object in a mirror. Note the position of the object and also the position of the virtual image, which is seemingly behind the mirror.

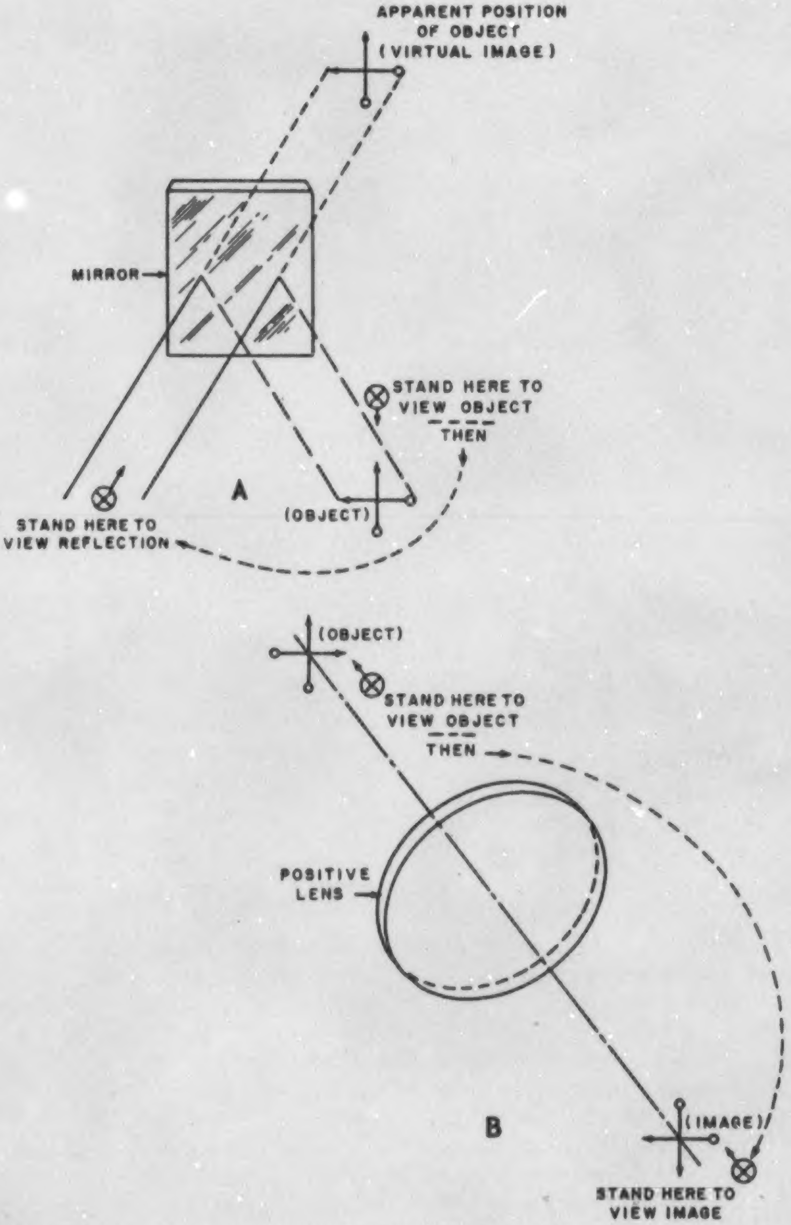
Part B of figure 3-6 shows you where to stand to view an object and where to stand to view on plate glass or a screen, the image of that object created by a positive lens. (The straight line through the center of the lens is the optical axis.) Lenses are discussed in detail in chapter 4.

IMAGE TRANSMISSION

Image transmission by use of a mirror or prism is, in fact, light reflection and refraction put to practical use. The mirror or prism is mounted so that it will transmit light from an object to whatever point is desired. Remember, mirrors and prisms do not produce images, they merely alter the path of light and the attitude of objects viewed through these optical elements.

PLANE MIRRORS

In a dark room, if you view a tiny point of light in a mirror, the point of light appears to be located behind the mirror and on the other side of the room from where it actually is. You see along the path of the reflected ray to the point where the incident ray is reflected by the mirror (eye "A," fig. 3-7). Your line of sight is extended in your mind in a direct line through and beyond the mirror. The apparent position of the point of light in the mirror is located directly across the room from the light source

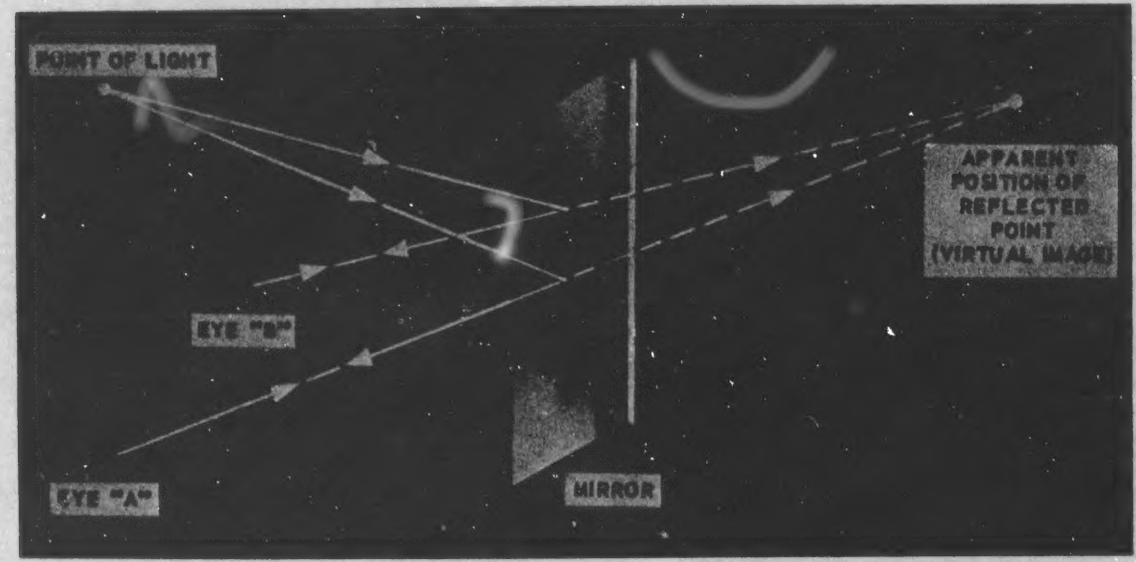


A. POSITION TO STAND FOR VIEWING AN OBJECT ITSELF AND THE POSITION TO STAND FOR VIEWING THAT OBJECT IN A MIRROR.

B. POSITION TO STAND FOR VIEWING AN OBJECT AND THE POSITION TO STAND FOR VIEWING THE IMAGE OF THAT OBJECT CREATED BY A POSITIVE LENS.

137.52

Figure 3-6.—Viewing objects and image attitude altered by optical elements.



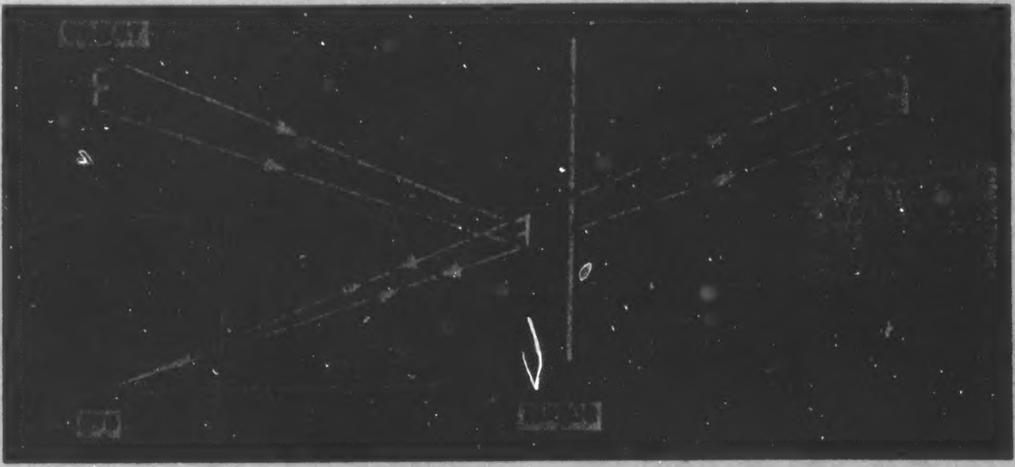
137.53

Figure 3-7.–Apparent positions of a point of light reflected by a plane mirror.

and at the same distance behind the mirror as the light source is in front of the mirror.

As long as you can see the reflection of the point of light in the mirror, regardless of your location in the room, its apparent position is unchanged. Observe the line of sight of eye "B' in figure 3-7. The point of light (object) is reflected, and the apparent position of its reflection is changed only when the position of the object or the mirror is changed.

If you replace the point of light (source) with a letter covered with luminous paint (F, fig. 3-8), light from every point on the letter sends out incident rays which are reflected by the

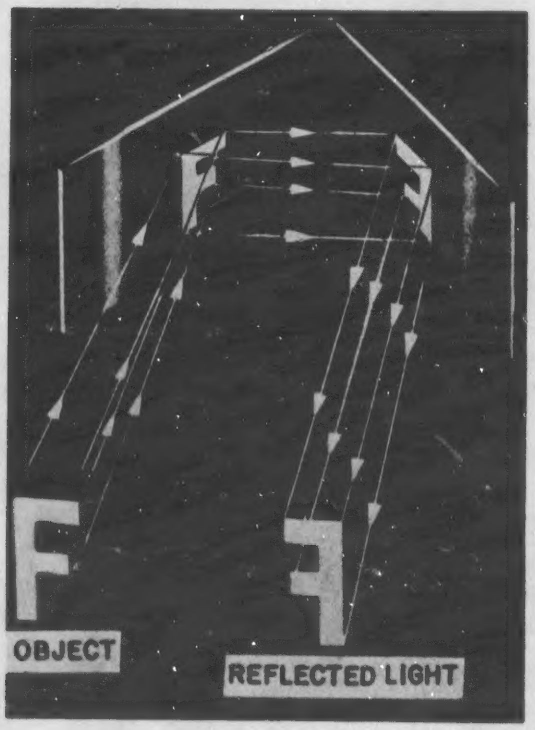


137.54

Figure 3-8.–Apparent position of an object reflected by a plane mirror.

mirror. Each incident ray and/or reflected ray obeys the laws of reflection and their paths can be plotted accordingly. The entire object is seen as a combination of an infinite number of individual points of light, consequently reflected to your eye. As you look along the paths of the reflected rays, you see the object seemingly back of the mirror and in an erect, reverted attitude.

A single mirror can be so mounted that it will reflect light for a practical purpose. An adjustable mirror on a car fender is a good example of such reflection. If the object cannot be reflected satisfactorily with a single mirror, a second mirror can be so placed that it will reflect light from the first mirror and retransmit it. Figure 3-9 shows how mirrors can be arranged so that they will change the line of sight.



137.55
Figure 3-9.—Attitude of an object produced by two plane mirrors placed at right angles.

The two mirrors shown in figure 3-9 are placed (mounted) together in such a manner that they form a 90° angle. Light from an object (F) strikes the reflecting surface of one mirror and is reflected by the first mirror to the second mirror, which reflects them again in rays parallel to the original rays. The light reflected by the two mirrors is, therefore, reflected a total of 180°. Also, since the two mirrors are mounted so that you are looking at the back of the object (F), the image attitude is unchanged in relation to the object. If you were to stand between the mirrors and the object (F), the object would appear as (ꟻ), which is exactly what is seen as a result of the two reflections from the mirrors.

NOTE: Review the information given earlier in this chapter concerning the comparison of images with their objects.

REFRACTING PRISMS

A prism is a piece of glass whose surfaces are flat, but at least two of the surfaces are not parallel. Prisms are generally made from borosilicate crown glass, because it has high resistance to abrasion and damage by atmospheric elements. Some prisms are used for both refraction and reflection in military optical instruments. Much of your repair work in the optical shop concerns them and, therefore, you should understand fully how prisms act in controlling the direction of light.

Unlike a lens, a prism is a block of glass constructed with plane surfaces, and it can be designed to refract and reflect light in numerous ways. The use of prisms in optical instruments, therefore, permits variations in design which otherwise would be impossible. Plane mirrors, for example, are sometimes used to change the angles of light rays, but the silvered surfaces tarnish and cause loss of light which becomes more serious as the instrument becomes older. A prism, on the other hand, can be mounted in a simpler and more permanent mount and used for the same purpose.

The surfaces of a prism are not easily disturbed, and a prism can produce more numerous reflection paths than a mirror. Prisms are used singly or in pairs for changing the direction of light from a few seconds of arc (measuring wedges) to as much as 360 degrees.

Review figure 2-27 which shows how light is refracted by a prism. Note that the incident ray of light is bent toward the NORMAL of the front face and away from the normal of the rear face (surface). Observe, also, the angle of deviation which is a measure of the amount of change in direction of a light ray caused by a prism.

Wedge

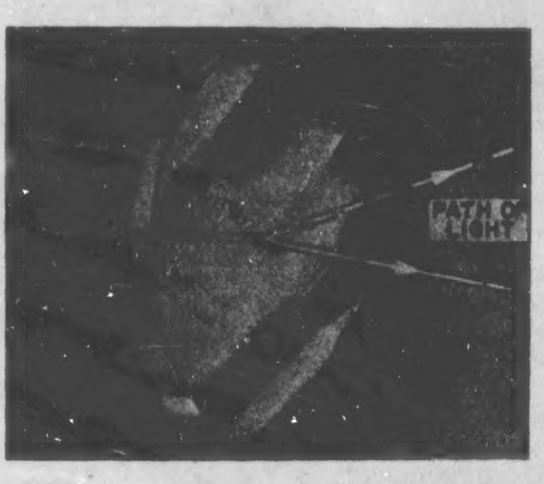
Prisms with the two plane surfaces at slight angles, which divert the paths of light through angles by refraction instead of reflection, are called optical wedges. Optical wedges are used in fire control instruments; they may be used where the angle of deviation required is a matter of fractions of seconds.

The angle at which a wedge diverts a path of light depends upon the angle between the entrance and emergence faces and the index of refraction of the glass.

Some wedges used in fire control instruments appear to be disks or plates of glass with parallel surfaces, because the angle between the surfaces is so slight it cannot be detected except by actual measurement. All wedges cause a certain amount of deviation in the path of light which passes through them. Some instruments which use wedges are therefore designed to create a definite amount of initial deviation of a ray of light when it leaves the wedge. This deviation is used to correct for errors in the path of light occurring in an optical system.

It is possible to change the path of light passing through a wedge by rotating the wedge. See figure 3-10. The solid path of light represents the deviation of light in the original position. The dotted path is the result of rotating the wedge 180°. The extent to which a wedge diverts the path of light may also be varied by changing the position of the wedge in relation to the other elements of the optical system, as shown in figure 3-11A.

Another method for changing the path of light by prisms is through the use of pairs of wedges geared to rotate in opposite directions. Two or four elements are used and they are referred to as ROTATING WEDGES or ROTATING COMPENSATING WEDGES. Figure 3-11B shows how light is refracted by wedges in three different positions.



137.112

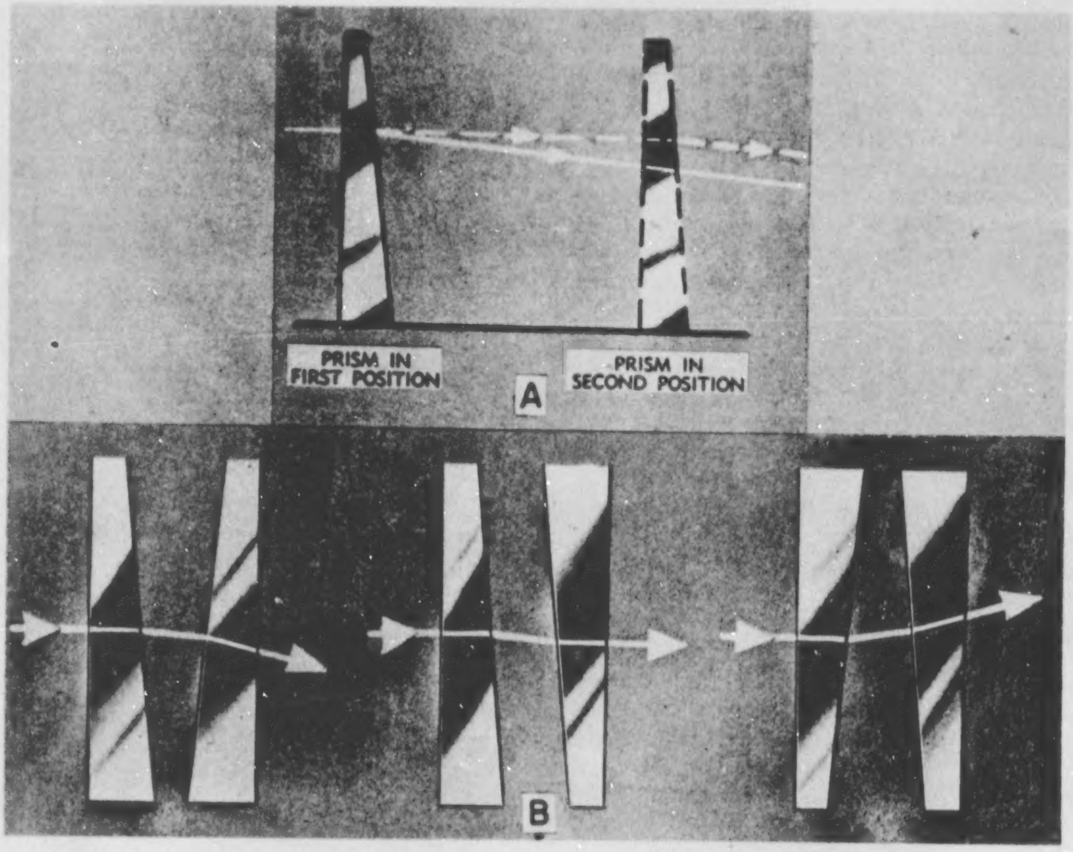
Figure 3-10.—Direction of light changed by a rotating wedge.

Prism Diopter

The dioptric strength of a prism is a measurement of the distance the refracted ray of light deviates from the path of the incident ray at 1 meter from the prism. Study figure 3-12. A prism of 1 diopter bends light to such an extent that when a refracted ray travels 1 meter beyond the prism it deviates a distance of 1 cm from the path of the incident ray. If a prism has a power of 2 diopters, for example, the deviation of the refracted light passing through it is 2 cm at a distance of 1 meter from the prism, and so on.

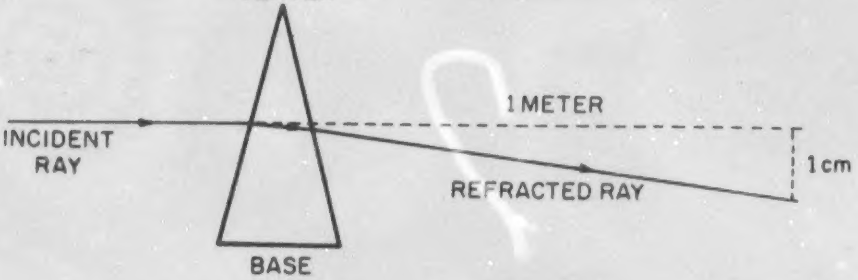
REFLECTING PRISMS

Most of the prisms used in optical systems are reflecting prisms. Deviation of light by a reflecting prism is brought about by internal, regular reflection. Some of the most common types of reflecting prisms are discussed in the following pages.



137.113

Figure 3-11.—Path of light changed by pairs of prisms rotating in opposite directions.



137.114

Figure 3-12.—Prism diopter.

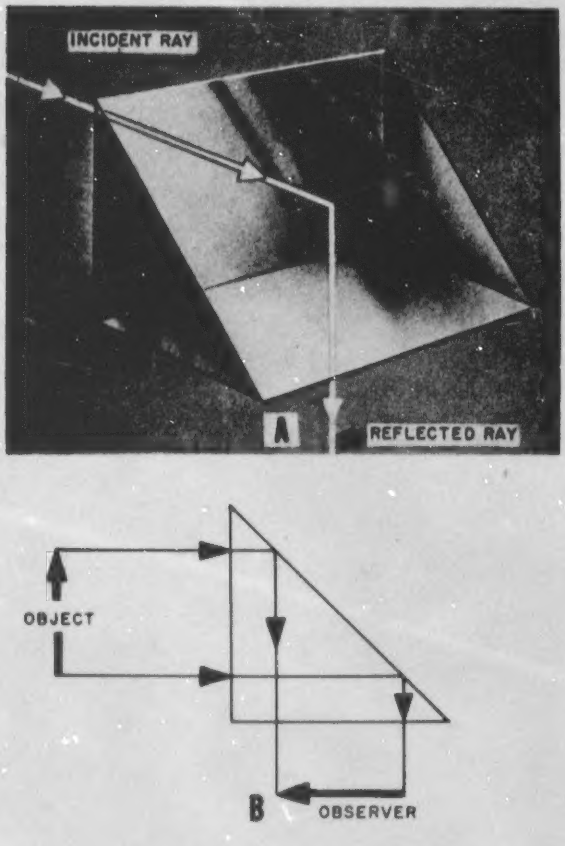
Right-Angled Prism

From a side view, the shape of a right-angled prism (fig. 3-13) resembles an isosceles right-angled triangle. Prisms with this basic shape are used in many ways in optical instruments.

The name of a right-angle prism implies that it gives reflections of 90° only, but the prism can actually be used to give reflections at a great number of angles. If a right-angle prism is rigidly mounted and only rays of light parallel to the normal on a side opposite the hypotenuse are permitted to enter, the rays are not refracted upon entering and leaving the prism—they are merely reflected by the hypotenuse at a true 90° angle. When the prism is used in this manner, incident light strikes the reflecting surface at an angle greater than the critical angle so total internal reflection occurs. Therefore the reflecting surface does not need to be silvered.

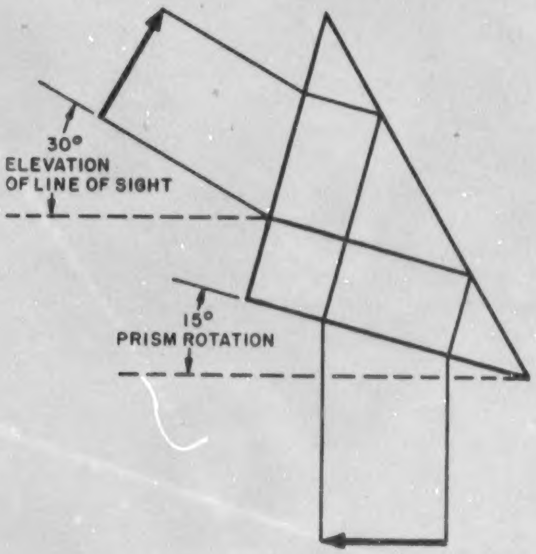
When a right-angled prism is mounted so that the reflecting hypotenuse can be tilted at various angles, it can be used to elevate and depress the line of sight as illustrated in figure 3-14. This arrangement is used in gunsights and periscopes, and the angular displacement of the line of sight is double the angular tilt of the prism. Also, notice the refraction of light that takes place at the entrance and emergence faces of the prism. With the prism used in this manner, the incident light may strike the reflecting surface at an angle less than the critical angle and emerge from the prism. For this reason, the reflecting surface is silvered so that all light striking the reflecting surface will be usable.

If you hold a right-angle prism so that your line of sight is deviated to the left or right, all the objects you observe will appear erect and reverted (reflection in the horizontal plane). When you hold the right angle prism so that your line of sight is deviated up or down, all



137.115

Figure 3-13.—Right-angled reflecting prism.



137.495

Figure 3-14.—Right-angled prism as elevation prism.

objects that you observe will appear normal and inverted (reflection in the vertical plane).

Porro Prism

A porro prism is actually a right-angled prism used in a different manner. When the hypotenuse of a right-angled prism is used to receive incident rays of light and exit the same rays after the other two faces of the prism reflect them, the prism is called a porro prism.

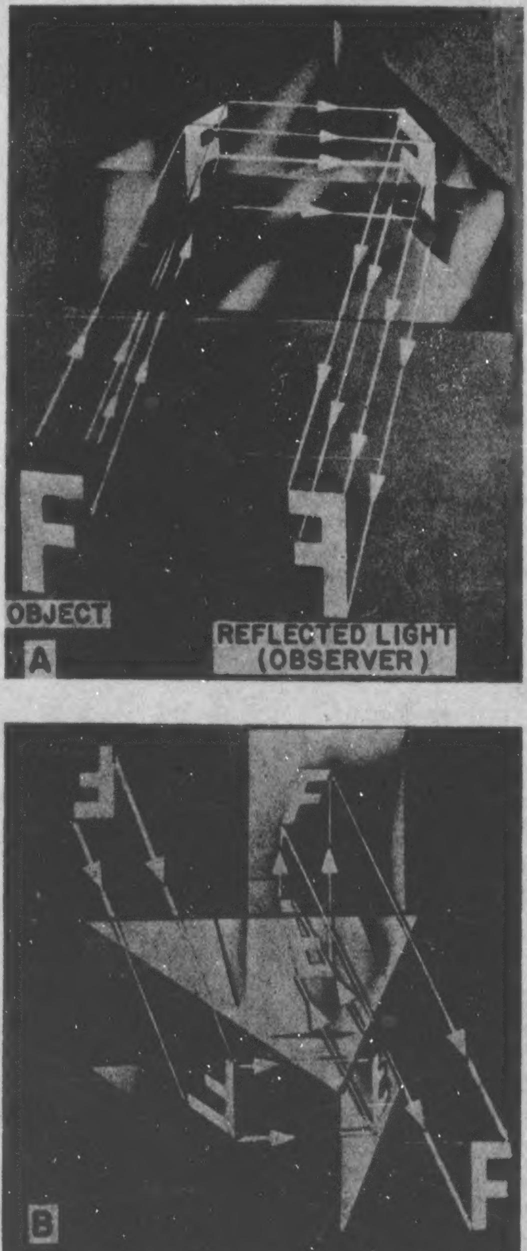
Review figure 3-9 and study figure 3-15; observe that the line of sight is reflected a total of 180°. Note also that the letter F appears reverted; but when you apply the image attitude rule, you find that it is normal. You can prove that this is true by the following experiment. Hold a book so the printed pages are facing away from you. Hold a porro prism in the horizontal plane as in figure 3-15A and lay the hypotenuse face on a page so that half the prism is extended over the edge of the book. When you look into the exposed face of the prism, the printing you see is completely normal. Now rotate the prism 90° so that half the prism extends over the top of the book. When you view the printing in this manner everything appears to you inverted and reverted.

Porro prisms are never used singly, they are mounted in pairs as shown in figure 3-15B. This arrangement is called a porro prism cluster, and an object viewed through it will appear inverted and reverted. The porro prism cluster is used effectively as an erecting system in many optical instruments such as binoculars and gunsights. The reflecting surfaces do not require a silver coating because the angle at which light strikes them is greater than the critical angle of the material from which the prisms are made.

Dove Prism

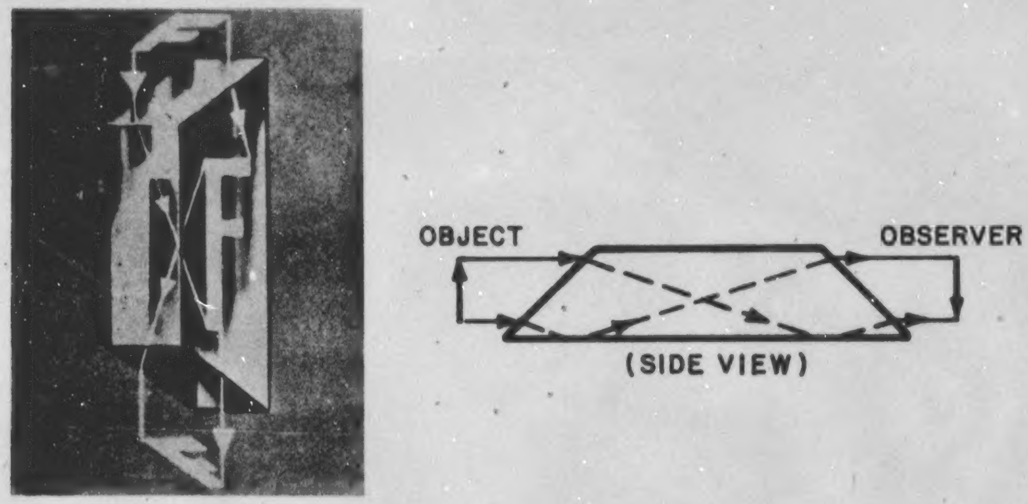
A dove prism (fig. 3-16) resembles a right-angled prism with its 90° angle sliced off. Light rays which enter one end of the prism are refracted to the longest face and reflected to the opposite face, from which they are refracted out of the prism in the same direction they were traveling before they entered the prism.

An object viewed through a dove prism, when the base (reflecting surface) is down, will



137.116

Figure 3-15.—Object viewed through single porro prism and porro prism cluster.



137.117

Figure 3-16.—Dove prism.

appear inverted. When the prism is rotated 90° in either direction, the same object will appear erect and reverted. If the prism is then rotated 90° so the base is up, the object will again appear inverted. Notice that the prism has been rotated through 180° and at the same time the attitude of the object has changed 360°. Any object viewed through a rotating dove prism will appear to rotate twice as fast in the same direction. To provide the best possible view of an object, the reflecting surface of the dove prism is silvered.

RHOMBOID PRISM

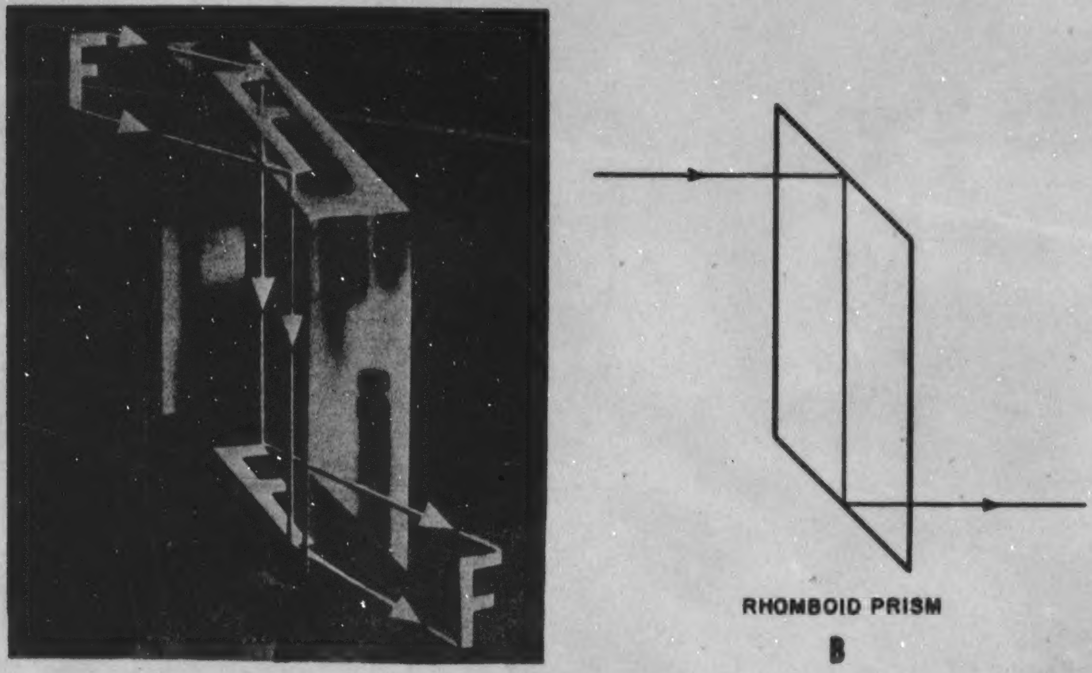
A rhomboid prism is a parallelogram with the upper and lower opposite faces cut at an angle of 45° and parallel to each other. Study figure 3-17.

The rhomboid prism has two parallel reflecting surfaces which provide two reflections in the same plane and transmit the line of sight unchanged. (The reflecting surfaces are not silvered.) It does NOT invert or revert the object or change the direction of light rays, but it OFFSETS the light rays from their original direction.

Regardless of the manner in which you hold or rotate a rhomboid prism about the line of sight, the attitude of an object viewed is ALWAYS erect and normal. The only purpose this prism serves is to offset the line of sight to make a new line of sight parallel to the old line of sight.

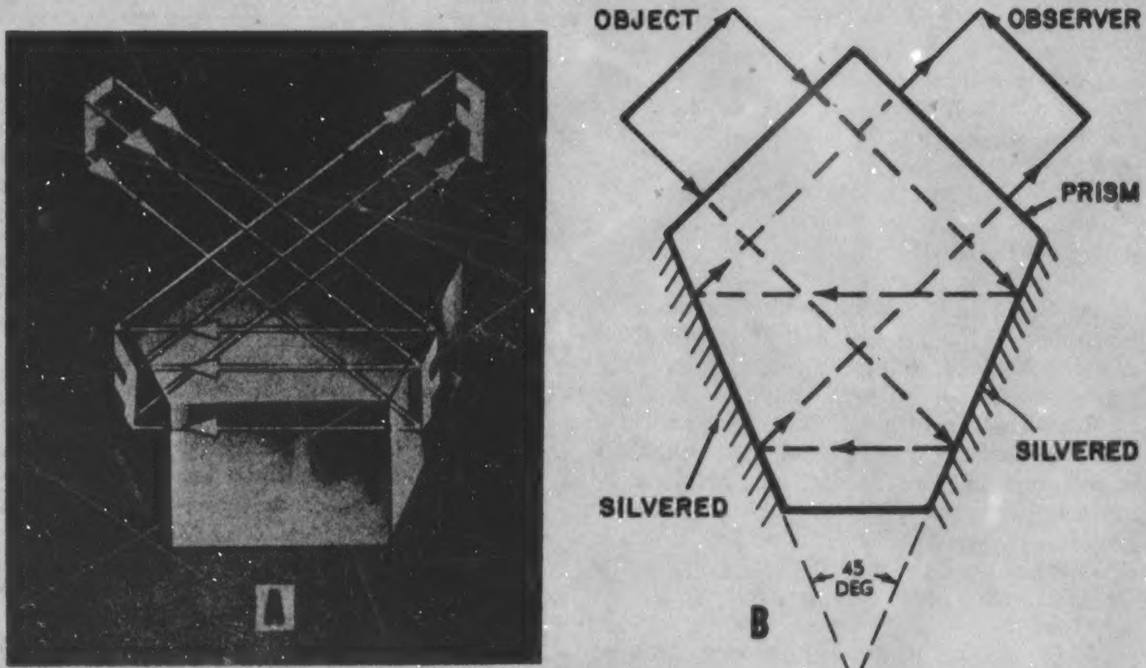
PENTA PRISM

A penta prism, shown in figure 3-18, reflects light from two reflecting surfaces by an amount equal to twice the angle between the reflecting surfaces. See figure 3-18B. If the angle between the silvered surfaces is 45° (prism angle), the deviation will be 90°; if the prism angle is 43°, then the deviation of the prism is 86°. (Remember that deviation is measured from where the incident light would have gone to where the emerging light goes.) When a penta prism is held so that reflection takes place in the horizontal plane or vertical plane, all objects viewed will be normal and erect. The prism may even be rotated slightly without changing the apparent position of the object viewed. This is called CONSTANT DEVIATION. There will be a slight amount of refraction at the entrance and emergence faces, but the refraction is equal and in the same direction. Therefore, the line of sight between the target and observer does not change. The constant deviation feature of the



137.118

Figure 3-17.—Rhomboid prism.



137.119

Figure 3-18.—Penta prism.

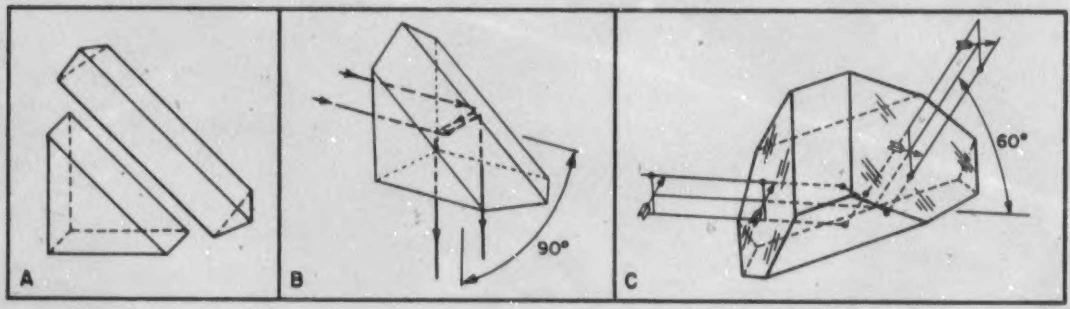
penta prism is very useful in rangefinders which rely on optical wedges to precisely measure the deviation of the line of sight.

Roof Edge Prism

You will easily understand the construction of a roof edge prism by referring to figure 3-19A. Light enters perpendicular to one surface, reflects left to right and right to left from the roof edge, and is also reflected to emerge perpendicular to the second surface. Light reflected from the roof edge in this manner will cause objects to appear inverted and reverted.

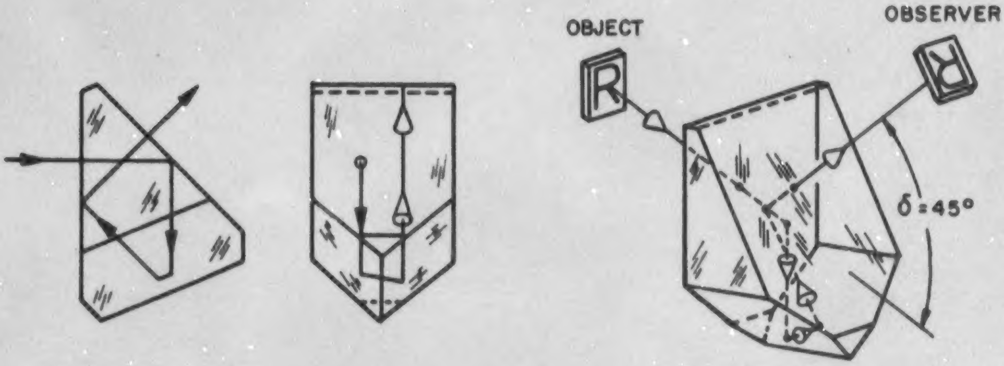
A roof edge prism may be ground so that deviation of the line of sight is 90° (fig. 3-19B) or 60° (fig. 3-19C). A 90° roof edge prism is sometimes called an Amici prism. Whatever the deviation of the prism, light will always enter and leave the prism perpendicular to the entrance and emergence faces.

The reflecting surfaces are not silvered, but the roof edge must be protected against chipping. Any chips on this edge will show up in the line of sight.



137.496

Figure 3-19.—Roof edge prism.



137.563

Figure 3-20.—Schmidt prism.

Schmidt Prism

A Schmidt prism, illustrated in figure 3-20, is used to erect and deviate the path of light in small navigation instruments. Its function is quite similar to the roof edge prism.

Light enters perpendicular to the entrance face and is reflected down to the roof edge from the back surface of the prism. At the roof edge, light reflects left to right and right to left and is then directed toward the entrance face, where it is again reflected, and emerges perpendicular to the emergence surface.

The reflecting surfaces of a Schmidt prism are not silvered because all reflection takes place at an angle greater than the critical angle.

Prism Defects

For a prism to perform its function in an optical system, it must first be produced from the correct type of glass, and it must be free of strain and internal defects. Secondly, the surfaces of the prism must be perfectly flat and ground to precise angles so that the path of light is directed in the exact direction desired.

Any differences in the density of glass from which a prism is constructed will cause distortion of the line of sight. Likewise, bubbles or foreign objects in the glass can produce distortion or reduce light transmission.

CHAPTER 4

LENSES

The basis for the construction of any optical instrument is to control the light traveling from an object so that the object is viewed more effectively with the instrument than with the naked eye. Of all the various optical elements used to control light, lenses are the most important and most widely used. Like the prisms and mirrors you studied in the previous chapter, lenses are made from high quality optical glass.

PROPERTIES OF GLASS

Ordinary and optical glass differ greatly in their chemical composition and also in the manufacturing process. The only common characteristic of all glass is that it is AMORPHOUS. This means that glass does not have a definite or crystalline form as solid bodies do.

PHYSICAL PROPERTIES OF GLASS

The properties of glass are explainable only if we assume that they have the same molecular arrangement as a LIQUID. When a crystalline body passes from a liquid to a solid state, the transition takes place at a definite temperature and is accompanied by considerable heat which temporarily halts solidification. With glass, on the other hand, the transition from the liquid state is so continuous and gradual that the most delicate instruments have failed to record either evolution of heat or retardation of the solidifying process, which is a gradual stiffening without change of structure. All glass, however, assumes a crystalline structure (devitrification) if, while in the vitreous state, the temperature is maintained too long at the critical state (crystallization point). Crystalline glass gives DOUBLE refraction, and a lens made from it forms two separate images at the same time.

Since glass has no melting point, when heat is applied to it gradually, it gets soft and can be molded into a thread; when it is red hot, it flows in a thick mass. A temperature of several thousand degrees will turn glass into a fluid.

In a fluid state, glass is a mixture of certain chemicals in solution. The most common chemicals used for this purpose are the silicates and borates. Under ordinary conditions of cooling, these chemical solutions remain mutually dissolved.

Although glass is a liquid, it is also a solid. Solids are characterized by definite shape and volume. Crystalline solids, for example, have a regular arrangement of particles; amorphous solids, on the other hand, have a random arrangement of particles—large, long-chain entangled molecules.

You perhaps wonder how anything as solid as glass can be a liquid or in an amorphous state. The reason for this condition of glass is that the molecules are held together in crystals by Van der Waals forces, which means that the electric field of the atoms of one molecule causes a similar variation in the electrical field of the atoms of another molecule to generate attraction between them.

To prove that glass is amorphous, place a thin-walled glass tube approximately 5 feet long on two nails driven into the bulkhead of your shop equidistant from the deck and observe the bend in the tube during a 5- or 6-months' period. Hold the glass tube against the bulkhead and mark its original position with a pencil, so that you will be able to measure the amount of bend which develops during the period.

One interesting thing about this test is that when you first place the tube of glass on the nails it shows a slight bend, which immediately disappears if you then remove it from the nails. At the end of your test, however, the bend will remain in the tube when you remove it from the nails because the liquid glass has actually flowed to its new position.

OPTICAL QUALITIES

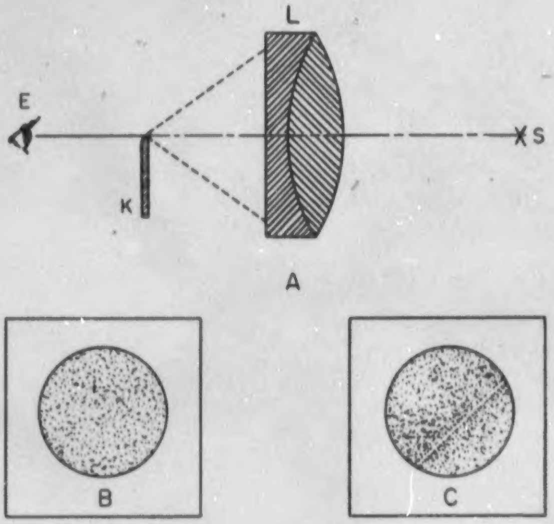
The purely optical characteristics which directly influence light as it passes through glass include: (1) homogeneity, (2) transparency, (3) freedom from color, (4) refraction, and (5) dispersion.

Homogeneity is the most important quality of optical glass. If you examine a thick piece of ordinary glass, you will find that the layers of different densities show clearly in the form of internal irregularities, known as VEINS or STRIAE, which are little streaks with a higher or lower index of refraction (bending) than the other part of the glass. Many times the striae are so small that they cannot be detected until the glass is ground (as a lens, for example) and polished. Because striae affect the sharpness of an image formed by the lens, this type of glass cannot be used in an optical instrument.

You can test a lens for striae in the manner illustrated in figure 4-1. If you place a light (S) behind a screen with a hole in it directly in front of the light and then hold a lens (L) with one hand and a knife blade (K) at the point indicated in the other hand, you can look along the optical axis (central point) of the lens and detect the absence or presence of striae. If the lens has no striae, the field appears dark (part B, fig. 4-1); if the striae are present, they show as bright lines (part C, fig. 4-1).

To be homogenous, a lens must also be free of dust, dirt, and bubbles. A few bubbles in a lens stop the passage of light through the lens at their location, but they do not hurt the quality of the image. The best lenses may have one or two bubbles, but inspectors of precision lenses reject lenses with more than three bubbles; they also reject a lens with only one bubble if the bubble is as big as half a millimeter in diameter.

The degree of absorption of light by glass varies with the color of the light. Optical glass must be free from color. When white light passes through glass, the glass absorbs more of one of its component colors than of the other colors, thus causing the emergent light to have a slight color tint. In thick pieces, purest and whitest glasses always show a distinct blue or green tint.



A. Testing procedure
B. No striae present
C. Striae present (white line)

137.1

Figure 4-1.—Testing a lens for striae.

Refraction and dispersion of light are two of the most important properties of any optical element. Refraction is the bending of a ray of light when it enters a lens or prism; dispersion is the separation of light into its component colors as it passes through a prism or lens. Dispersion occurs in an uncorrected lens or prism, because light is refracted differently for each wavelength.

Chemical stability is an essential feature of optical glass, because the best lenses would soon be useless if they were affected by moisture and traces of chemical fumes in the atmosphere. Condensed moisture on glass absorbs carbon dioxide and forms carbonic acid, which dissolves glass. Distilled water, for example, must be kept in specially made glass containers or bottles because it dissolves ordinary glass. High-quality optical glass (HARD CROWN and BOROSILICATE CROWN) resists chemicals and is therefore durable.

Another important feature of optical glass is MECHANICAL HARDNESS (generally accompanied by a low refractive index) because lenses must be hard enough to resist the effects of cleaning which must be accomplished as necessary. The difference in degree of hardness is a result of the elements used by the manufacturer to get desired optical qualities in the glass.

Another problem with optical glass which must be avoided is STRAIN. Strain can occur during the manufacturing process if the molten glass is not cooled (annealed) properly. When glass cools, it contracts; if the cooling takes place too rapidly, the surface will cool while the center remains hot. This uneven annealing causes internal stress which can make the lens shatter during grinding and polishing, or while mounted in an instrument.

Although desirable, entire freedom from strain is essential only for special optical purposes. Glass manufacturers know from experience the amount of strain permitted in glass intended for various uses.

You can test for strain in optical glass by doing the following: (1) mount two polaroid filters in line with a light, 1 inch apart; (2) look through the filters toward the light and turn one of the filters until the field is dark; and (3) while looking into the dark field, hold the test glass between the two polaroid filters. If the field remains dark, the glass is free from strains. Strained glass, on the other hand, rotates the plane of polarization, causing you to see rings or bands of colored light.

Raw materials used in making optical glass must be practically free from impurities because the transparency of glass allows you to see defects in the COLOR and QUALITY of the finished products. Although volatile and combustible substances are usually completely eliminated by high temperature during the melting step, all fixed (stable) substances, which compose the mixture, appear in the finished glass. The selection of raw materials for optical glass is therefore most important.

One thing to remember about optical glass components is that the greater the amount of lead used, the higher will be the index of refraction of the glass. For example: CROWN GLASS (fairly low index of refraction and dispersion) contains phosphorus, barium, or boron, but no lead; FLINT GLASS (higher index of refraction and dispersion than crown glass) may contain a small quantity of barium or boron, but it does contain lead.

LENSES

A lens is a transparent optical element that has two polished major surfaces opposite each other–one surface is CONVEX or CONCAVE in shape and is usually spherical.

Lenses are grouped into three categories: (1) thin lenses; (2) thick lenses; and (3) compound lenses. Basically stated, a THIN lens is so constructed that its thickness is not important in measuring the distances from the lens to the image and to the object. With THICK lenses, however, because of their thickness, you must make allowances when measuring the distances to the image and the object. A COMPOUND lens is composed of two or more separate lenses.

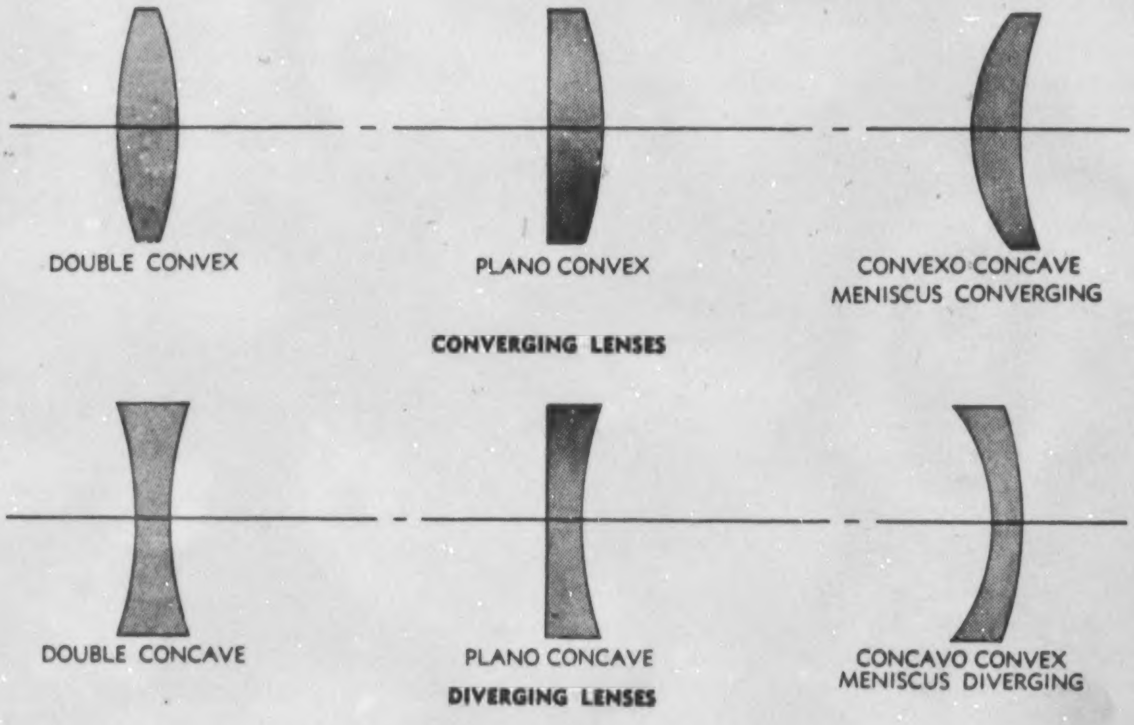
There are several, more technical considerations made in the grouping of lenses, but we will discuss only those affecting your work as an optical repairman.

Some types of thin lenses are illustrated in figure 4-2. Note the shapes of the opposing surfaces of these lenses and also observe that they are divided into converging lenses and diverging lenses. A convergent lens adds convergence to incident light rays by refraction. Convergent lenses are thicker at the center than at the edge and are called positive lenses. A divergent lens adds divergence to incident light rays. Divergent lenses are always thicker at the edge than at the center and are called negative lenses.

One important rule to remember when describing a lens is: READ THE SURFACES OF THE LENS ACCORDING TO THE DIRECTION OF THE INCIDENT LIGHT. In this manual, we always illustrate the path of light as going from left to right. In our discussion you will assume that light travels the same way.

LENS TERMINOLOGY

Before we go on with the study of lenses, you must understand some of the terms and phrases that apply to lenses and their use in optics. Refer frequently to the illustrations that are listed in these discussions.



137.69

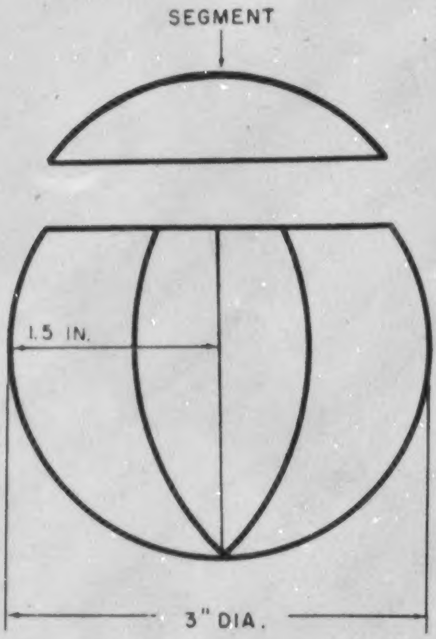
Figure 4-2.—Types of thin lenses.

CURVATURE

Curvature, as applied to lenses, is the amount of departure from a flat surface. Refer again to figure 4-2 and note the curvature of the lens surfaces. The surfaces appear to be only curved lines but, in effect, lens surfaces are spherical in shape. To visualize more clearly the surface of a lens, look at figure 4-3 which shows a segment of a sphere. The curvature of a lens surface is described as convex, plano, or concave. Convex surfaces are rounded like the exterior surface of a sphere; plano surfaces are flat; and concave surfaces are rounded inward like the interior surface of a sphere. If you consider the segment at the top as a lens, you would describe one surface as being plano on the flat surface and the other as convex.

RADIUS OF CURVATURE

In optics the term "radius of curvature" describes the amount of curvature of a lens surface. The radius is a line segment extending from the center of the sphere to the curved surface. Figure 4-3 illustrates a sphere with a diameter of 3 inches. The line segment, measured from the center of the sphere, is 1.5 inches and the radius of curvature is also measured as 1.5 inches. The radius of curvature is the primary factor in determining the refracting ability of a lens. The smaller the radius of curvature, the more light will be refracted.



137.497

Figure 4-3.–Sphere and segment.

FOCAL LENGTH

The focal length of all lenses is in the distance from the principal focus to the optical center. Figure 4-4 shows the focal lengths of a convergent lens; figure 4-5 shows the focal length of a divergent lens.

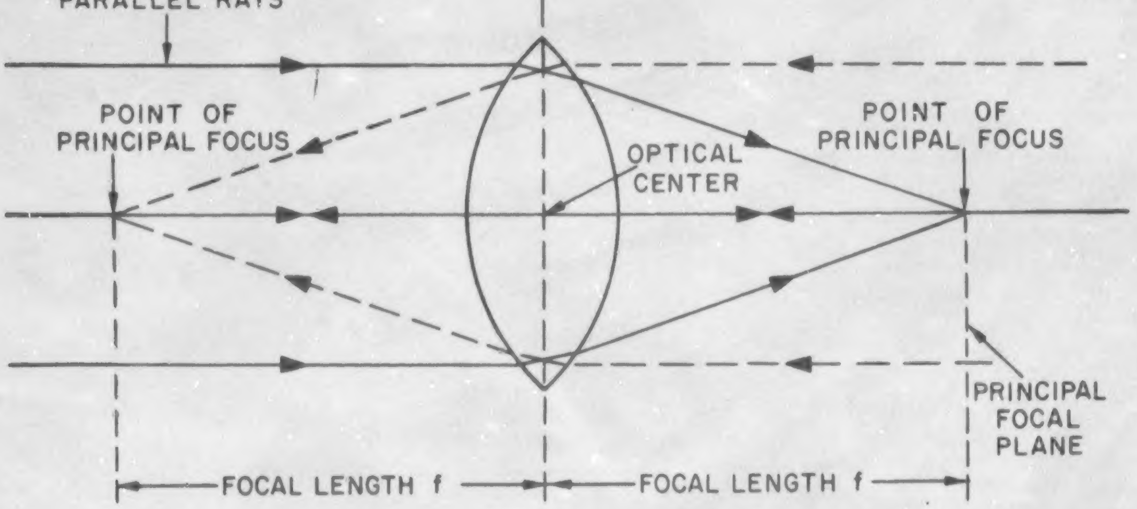
You can determine the approximate focal length of a convergent lens by holding the lens in a position to focus the image of an object at infinity on a sheet of paper or ground glass. When the image is clear and sharp, you have reached the point of principal focus; if you then measure the distance from the image to the optical center of the lens, you will get the focal length.

Optical Axis

Line AB in figure 4-6 is the optical axis, which is an imaginary straight line passing through the centers of curvature of both surfaces of a lens. Point A is the center of curvature of the rear surface of the lens; point B is the center of curvature of the front surface of the lens.

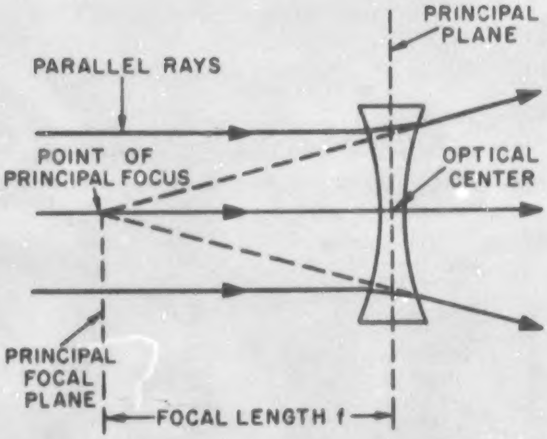
Principal Plane

Both thin and thick lenses have two principal planes which are imaginary planes at the point where the incident ray, if prolonged, would intersect the prolonged emergent ray. In figure 4-6 this plane is represented by line CD. Notice that incident ray B, parallel to the optical axis, is refracted upon entering and leaving the lens. If both the incident ray and the emergent ray are extended, as indicated by the dotted lines, they would intersect at "d" on the



137.77

Figure 4-4.—Focal lengths of a convergent lens.



137.78

Figure 4-5.—Focal length of a divergent lens.

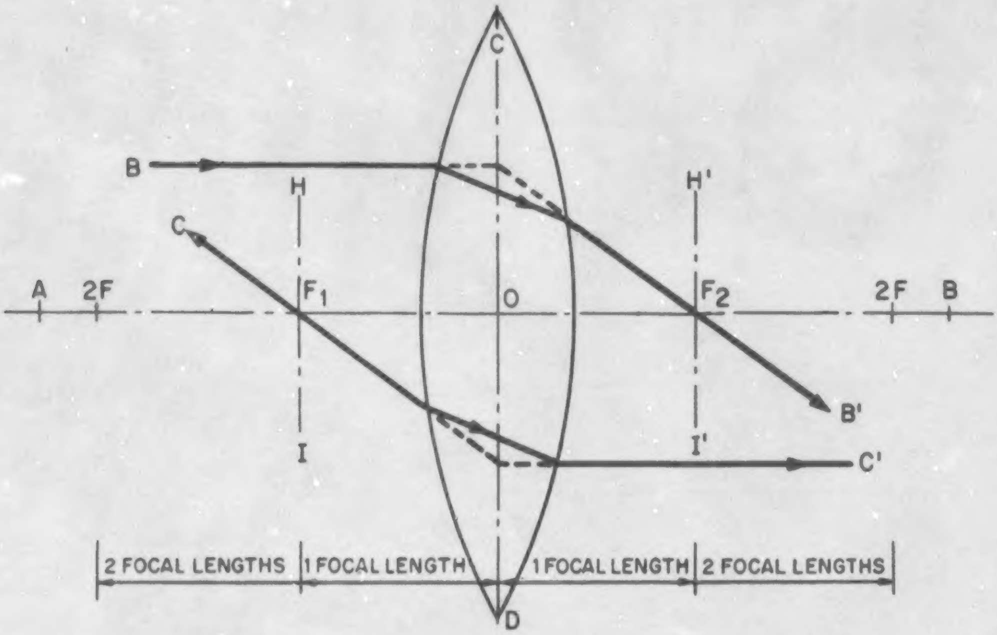
principal plane. In a thin lens with equal curvatures, the principal planes coincide. In thick lenses, or lenses with unequal curvatures, there will be two definite principal planes which can be located by using lines B-B′ and C-C′ as shown in figure 4-6.

Optical Center

The point in a lens through which light rays pass without deviation is the optical center. In thin lenses the optical center is located on the optical axis, halfway between the two curved surfaces of the lens. This is indicated by the letter "O" in figure 4-6; in a thin lens the optical center will be intersected by the principal plane.

Principal Focal Point (Principal Focus)

The principal focus is the point where parallel incident rays converge after they pass through a convergent lens. Every convergent lens has two points of principal focus, one on each side. The point of principal focus on the left side of the lens is the PRIMARY FOCAL POINT (F_1 in fig. 4-6); the point of principal focus on



137.76

Figure 4-6.—Lens terminology.

the right of the lens is the SECONDARY FOCAL POINT (F_2). The incident ray B is parallel to the optical axis and, after it is refracted by the lens, passes through the SECONDARY focal point F_2. Ray C passes through the optical axis at the primary focal point F_1, is refracted by the lens, and emerges parallel to the axis.

This may seem confusing but, if you refer back to Chapter 2 where you studied the Law of Reversibility, you will understand that a lens can have two principal focal points.

Principal Focal Plane

The principal focal planes are imaginary lines (HI and H'I') perpendicular to the optical axis at the points of principal focus (fig. 4-6). Even though a lens has two principal focal planes, there are other points where an image can be formed. Image formation will be fully explained later in this chapter.

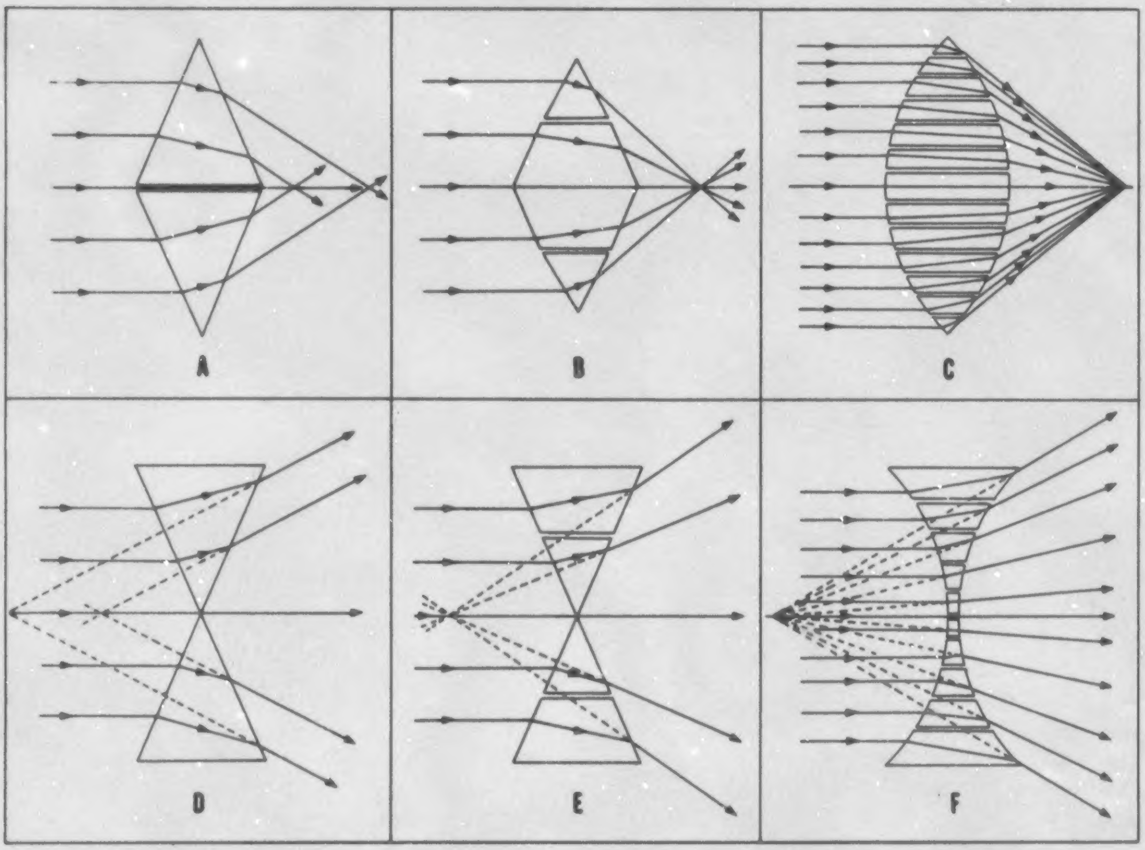
POSITIVE LENSES

Refer again to the group of converging lenses in figure 4-2. These lenses are called positive lenses because they will always converge light, regardless of surface curvature, as long as the lens is thicker in the center than at the edges. Look at figure 4-7 (Parts A, B, and C). Notice how a series of prisms can be arranged to refract light to a common focus.

If you apply the law of refraction to the ray in figure 4-8, you will understand what happens when it passes through a convergent lens. When an incident light ray enters a convergent lens (a medium more dense than air), it bends toward the normal; when the refracted ray (emergent ray) goes back into the air, it bends away from the normal. All parts of the surface of the lens behave in the same manner. Look again at figure 4-7 (A, B, C).

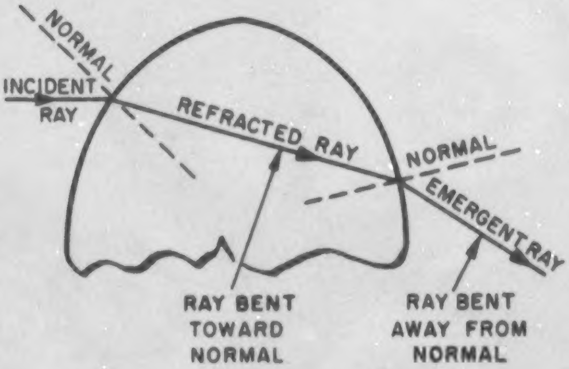
NEGATIVE LENSES

The diverging lenses shown in figure 4-2 are called negative lenses because they always



137.100

Figure 4-7.—Lenses constructed from prisms varying in number, size, and shape (principle of refraction shown).



137.71

Figure 4-8.—Refraction of light rays by a convergent lens.

diverge light, regardless of surface curvature, as long as the lens is thinner in the center than at the edges. Figure 4-7 (D, E, F) illustrates the path of light through a series of prisms assembled to duplicate a negative lens. Figure 4-9 shows how a single ray of light is refracted when it passes through a negative lens.

A positive lens converges incident light to a focal point which can be measured. A negative lens will not produce a real image; to determine its focal length, you must extend the emergent rays back through the lens to establish the imaginary focal length (fig. 4-7, parts E and F).

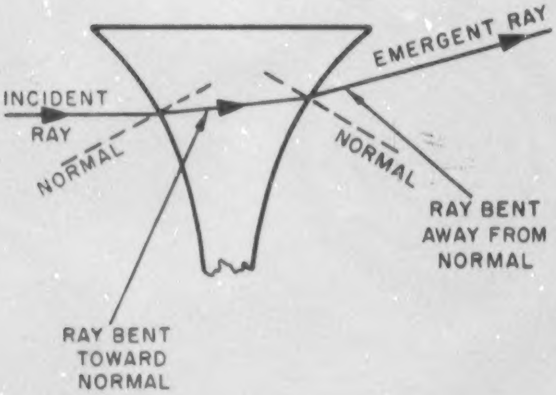
IMAGE FORMATION

As you know, light rays emanate from all points on an object and pass through a positive lens to a point of convergence behind the lens. This point is called the image point when the object is at a distance greater than the focal length of the lens.

Look again at figure 4-8 to see how the laws of refraction may be applied to plot the path of any light ray through any type of lens. Then, study figure 4-10 which shows how light rays pass through a convergent lens and converge at a single point.

Millions of light rays may come from every point of light on an object, but in figure 4-10 we use only three such rays to show how they pass through a convergent lens. As you learned previously in this chapter, the light rays, which strike a convergent lens on either side of the optical axis, refract toward the thickest part of the lens, and refract further when they emerge from it. As shown in the illustration, they converge to a single point.

A light ray that passes along the optical axis through a lens does not bend because it strikes the surfaces of the lens at the normal.



137.74

Figure 4-9.—Application of the law of refraction to a divergent lens.

Study figure 4-10 carefully. The central ray passes through the optical center of the lens and, even though it is not on the optical axis, does not deviate. Any ray of light passing through the optical center of a lens will actually be offset, but the deviation is so slight it is ignored.

Part A of figure 4-10 shows how three rays of light from object F are refracted to reproduce that point on the image Ⅎ. Every point on the object forms its point of light on the image in the same manner. Rays from the object form points of light on the corresponding image which is transposed diametrically and symmetrically across the optical axis from the object. This image is real, inverted, reverted, and diminished.

Principal Light Rays

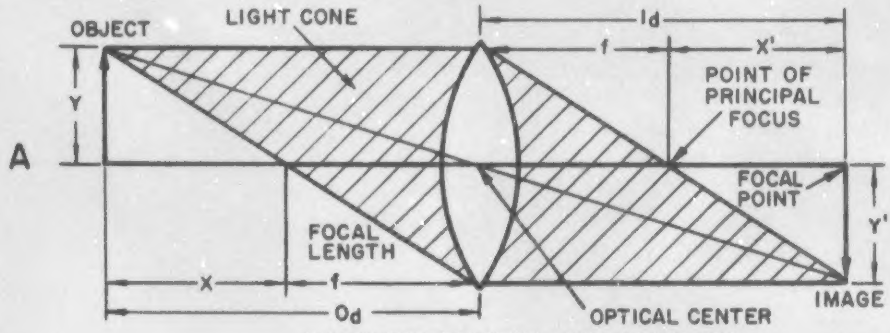
Refer to the four principal rays of light in figure 4-11. These rays are used to plot image formation in any lens, thick or thin. When these light rays pass through a lens, they ALWAYS follow definite rules. Line XY in the illustration is the optical axis of the lens. Notice that rays A, B, C, and D do not follow the law of refraction as shown in figure 4-8. This is done to simplify plotting image formation and to illustrate that refraction appears to take place in a lens at the principal plane (dotted line perpendicular to the optical axis).

LIGHT RAY A.—Any incident ray passing through the optical center (O in figure 4-11) of a lens and emerging from the lens without deviation from the path it was following before entering the lens.

LIGHT RAY B.—Any incident light ray which travels parallel to the optical axis of a lens, strikes the lens, and is refracted to the principal focal point F_2 behind the lens.

LIGHT RAY C.—Any ray which passes through the principal focal point F_1, strikes the lens, is refracted, and emerges parallel to the optical axis. NOTE: The C ray is opposite of the B ray.

LIGHT RAY D.—Any ray which passes through a point two focal lengths in front of a



SCHEMATIC DIAGRAM–CONJUGATE FOCI

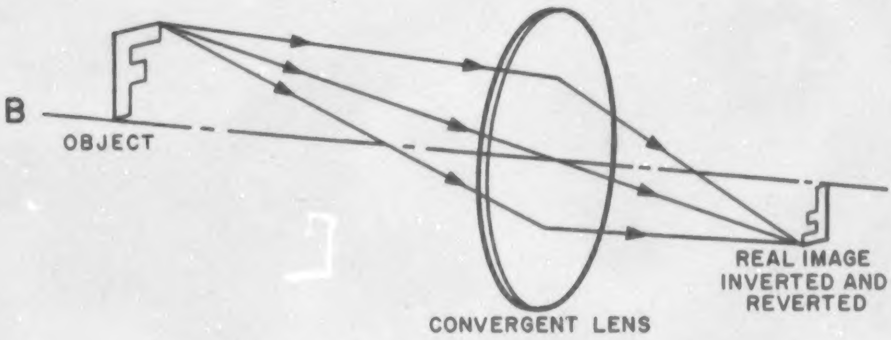


Figure 4-10.–Image formation by a convergent lens. 137.79

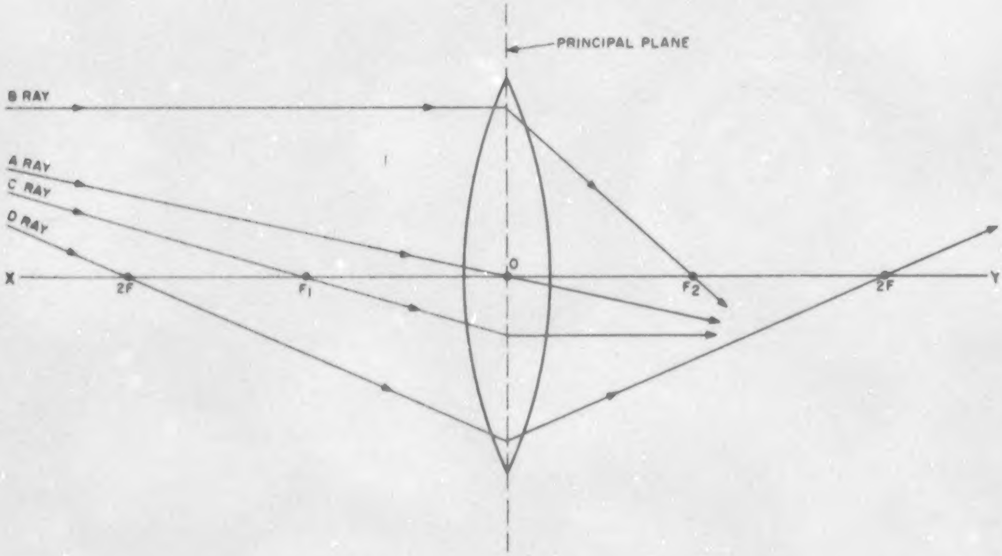


Figure 4-11.–Principal light rays. 137.70

lens, strikes the lens, is refracted, and converges to a point two focal lengths behind the lens. In accordance with the Law of Reversibility, this ray (and all other rays) could be reversed in direction.

The four principal light rays just discussed can travel to the lens from any angle as long as they follow the rules which pertain individually to them.

Positive Lenses

When an object is at a great distance (infinity), incident rays of light from it are parallel and the image is real, inverted, reverted, and diminished; the image is formed by the light rays at the secondary focal point.

If the object is at a distance beyond two focal lengths but less than infinity (fig. 4-12), a real, inverted, reverted, diminished image is formed between the secondary focal point and 2F on the opposite side of the lens. Note the size of the image in figures 4-12 through 4-17 as compared to the object. When an object is brought closer to a lens, the images formed become larger than images formed by the object at greater distances from the lens.

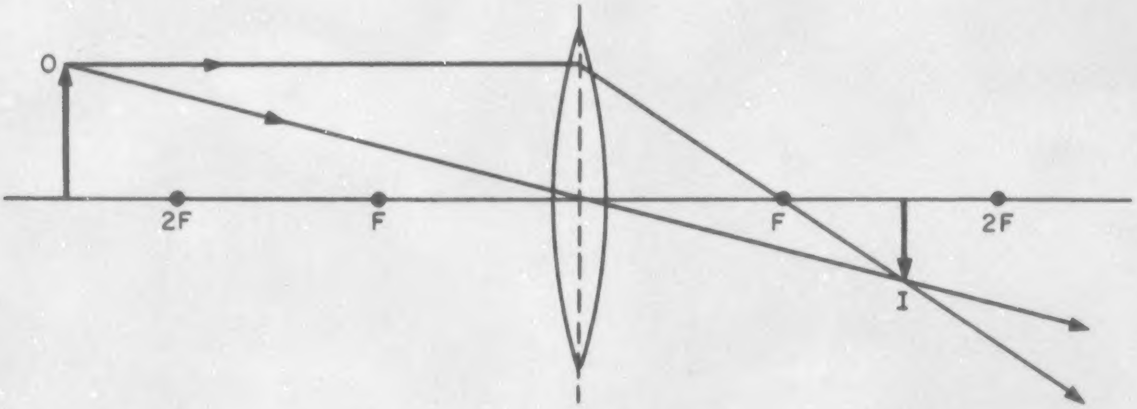
In figure 4-13 you see an object placed two focal lengths in front of the lens. The image the lens forms of this object is real, inverted, reverted, equal in size, and located at 2F on the other side of the lens.

When an object is at a distance between one and two focal lengths from a lens, as illustrated in figure 4-14, the image is real, inverted, reverted, and larger than the object, and at a distance of 3F on the other side of the lens.

Figure 4-15 shows an object at the principal focus of a lens; the emerging light from the lens is parallel and therefore cannot converge to form an image. The image in the illustration is in transition at infinity. A searchlight is an example of this type of image formation.

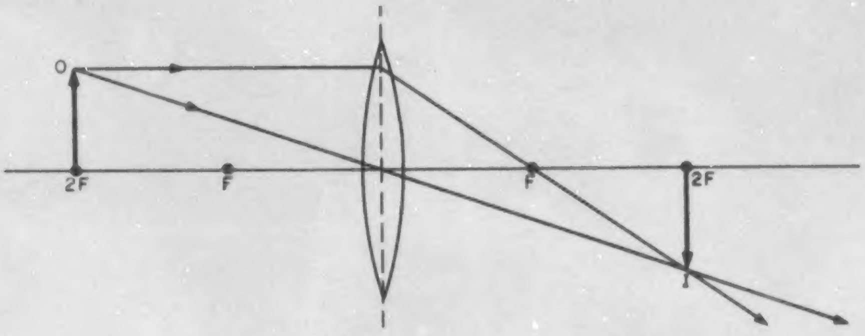
When an object is closer to a lens than the principal focus, divergence of the incident light is so great that the lens cannot converge or make it parallel. The emerging light from the lens is merely less divergent than the incident light, and the rays appear to come from a greater distance than the actual distance of the object. See figure 4-16. These rays appear to converge behind the object to produce an erect, normal, enlarged, and virtual image located on the same side of the lens as the object.

From this discussion of images created by objects, you will understand that (1) as you move an object closer to a lens, the image created by the object moves away from the lens, and (2) it becomes increasingly larger as it moves. When you move the object to the principal focal point of the lens, the image becomes virtual and is formed at infinity. When the object is located between the principal focal



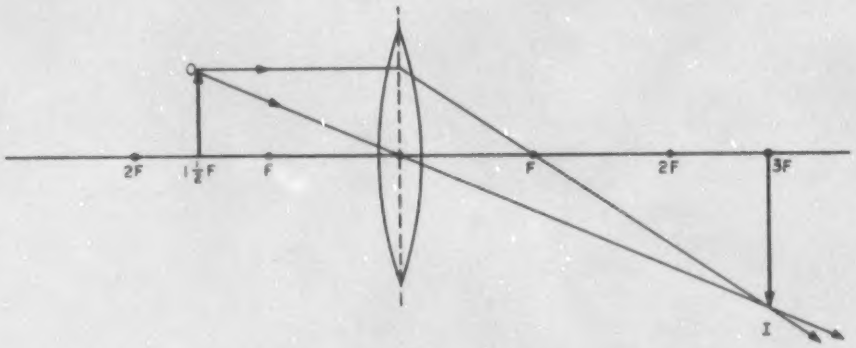
137.80

Figure 4-12.–Position of an image formed by a convex lens when the object is more than two focal lengths distant.



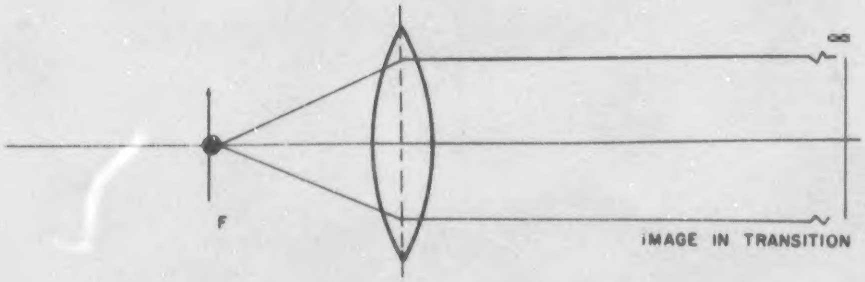
137.81

Figure 4-13.—Position of an image formed by a convergent lens when the object is at a distance equal to twice the focal length.



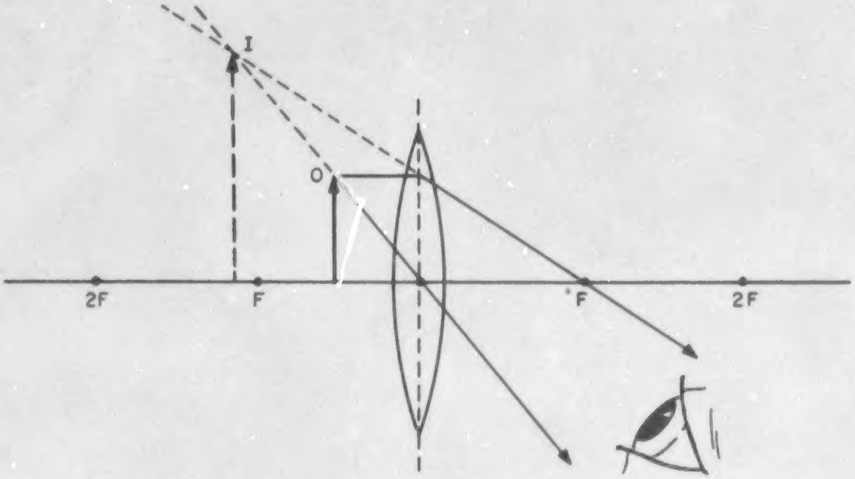
137.82

Figure 4-14.—Position of an image formed by a convex lens when the object is between the first and second focal lengths.



137.498

Figure 4-15.—Image formation by a convergent lens when the object is closer to the lens than the focal point.



137.84
Figure 4-16.–Formation of a virtual image by a convex lens when the object is closer to the lens than the focal point.

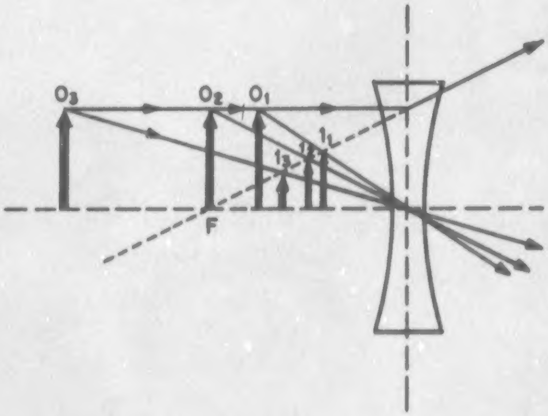
point and the lens, the lens becomes a magnifying glass.

Negative Lenses

The point of principal focus, focal points, and focal planes resulting from the nearness of an object or light source to a simple divergent lens are located on the side of the lens toward the light source or object. The point of principal focus and other focal points are located where the emergent rays should intersect on the optical axis if they were extended backward as imaginary lines toward the side of the lens on which the light strikes. Review figure 4-5 for terminology pertaining to a simple divergent lens.

If you use a page of this book as an object–at arm's length–and look at it through a divergent lens, this is what happens:

1. When the lens is in contact with the page (object), the image you see is erect, normal, virtual, and slightly smaller than the object.



137.88
Figure 4-17.–Image formation by a divergent lens.

2. If you move the lens away from the page, the image becomes even smaller.

3. When you have the lens quite close to your eye, you can see only a blur, regardless of the position in which you hold the object.

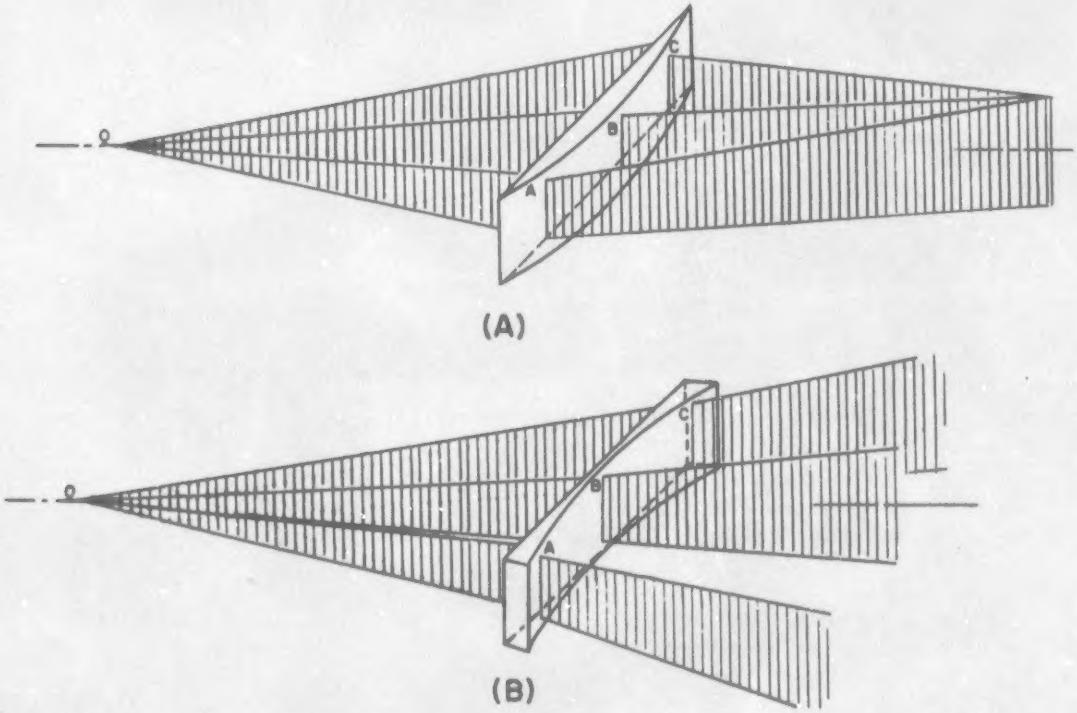
To see how a negative lens functions, refer to figure 4-17. The three arrows (O_3, O_2, O_1) on the optical axis represent a far, intermediate, and close object. The ray of light parallel to the optical axis is common to all three arrows, and separate rays are drawn from the arrows to pass through the optical center of the lens. The dotted line is an extension of the emergent ray. Arrows I_1, I_2, and I_3 show how objects O_1, O_2, and O_3 would look if you were observing them through the lens.

Refer to figure 4-11. Notice that the B ray and A ray were used to plot image formation in positive lenses discussed previously. Those two rays were also used to plot the virtual images in figure 4-17.

CYLINDRICAL LENSES

A cylindrical lens is an optical element whose surfaces (one or both) are portions of a cylinder rather then being ground as a portion of a sphere. See figure 4-18. Cylindrical lenses can be positive (A) or negative (B).

The positive cylindrical lens converts a point source of light (O in figure 4-18A) into a narrow line of light. This is useful in some optical



137.96

Figure 4-18.—Cylindrical lenses.

instruments as an indicating mark. The negative cylindrical lens converts a point of light into a broad band of lesser intensity. This lens is sometimes used to provide illumination using a small light bulb.

Positive and negative cylindrical lenses are often used in eyeglasses to correct vision defects (discussed later in the chapter).

SPHERICAL MIRRORS

You perhaps have been at an amusement park where a building designated as "Fun House" used curved mirrors to make you look ridiculously tall or disgustingly fat. Convex rear-view mirrors are also used on automobiles and trucks to give the drivers a wide view (field of vision).

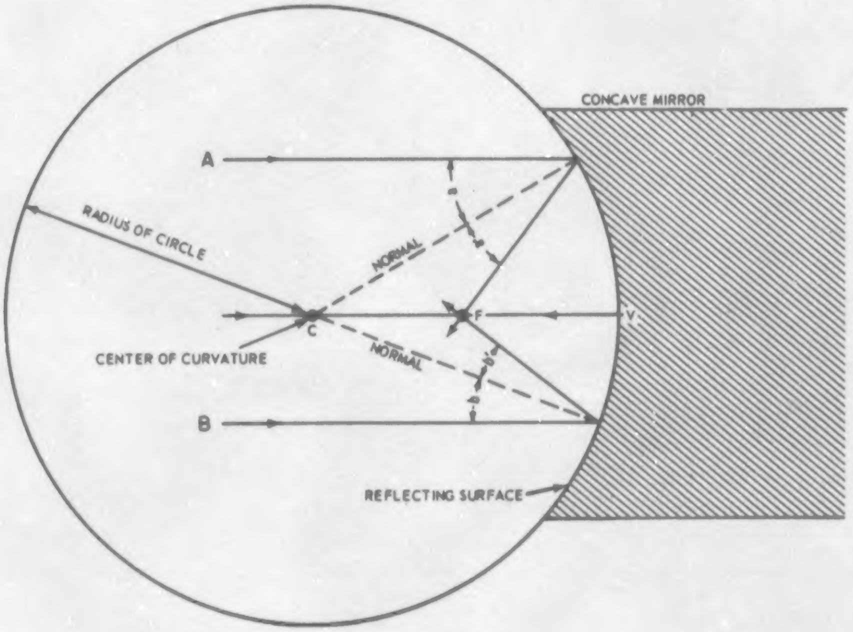
A spherical mirror either converges or diverges light. A positive (convex) mirror will diverge light striking it, and a negative (concave) mirror will converge light to a focus.

Concave Spherical Mirrors

It is important at this time that you learn the terms pertaining to a concave mirror. Refer to figure 4-19 as frequently as necessary during your study of the following discussion.

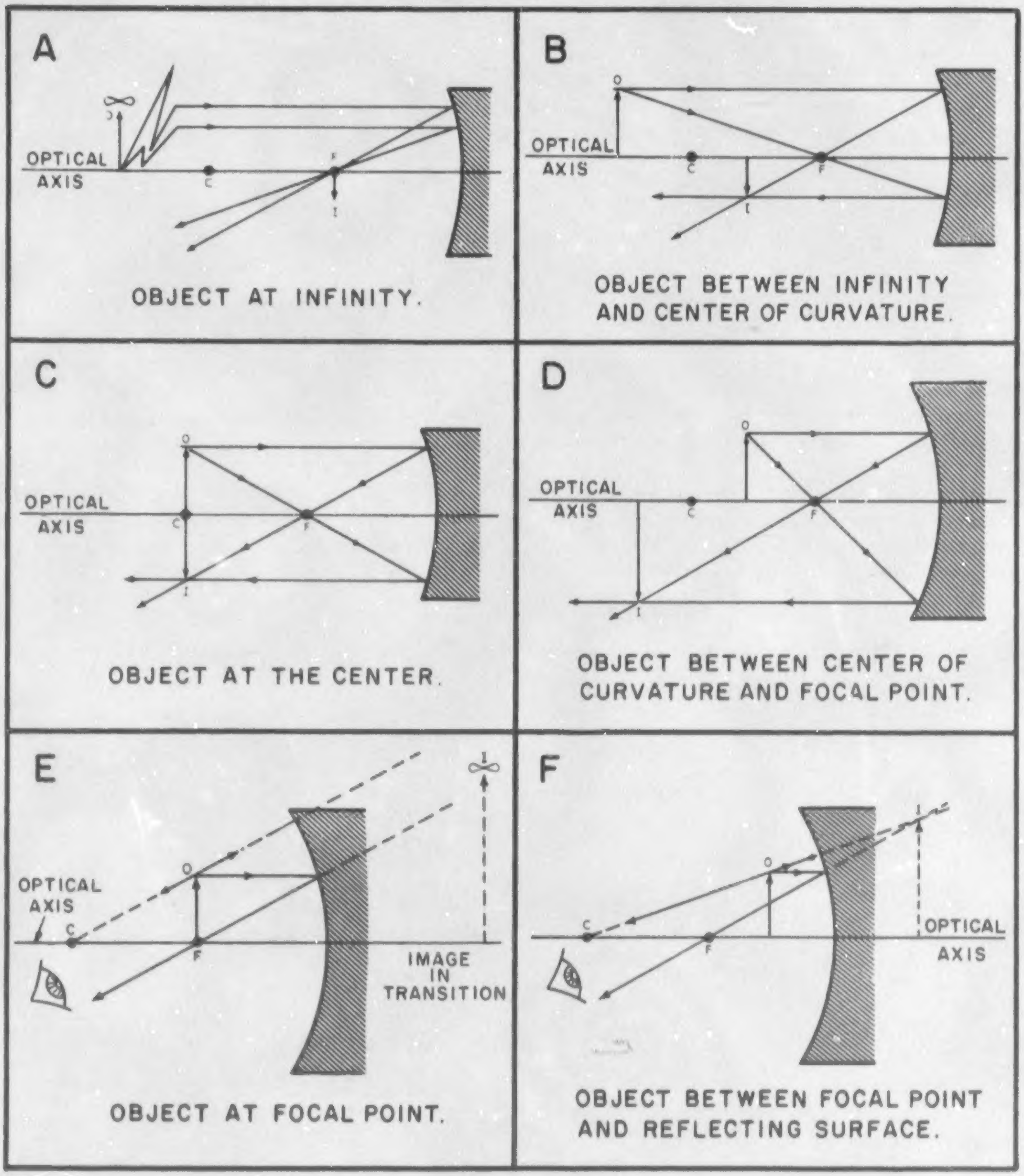
The degree of curvature of a spherical mirror varies according to the purpose for which it is intended. The procedure for making this kind of mirror must be by a specific formula.

Line CV in figure 4-19 is the radius of the size of a circle needed to produce the reflecting surface of the mirror. Point F, the focal point of this mirror, is located halfway between the center of curvature C and the mirror surface V. Parallel light rays A and B strike the mirror surface and converge to a common focus. The normals at the points of incidence are quite simple to accurately locate since they are nothing more than the radius of the circle used to construct the mirror.



137.56

Figure 4-19.–Construction of a concave mirror.



137.59

Figure 4-20.—Position of image formed by a concave mirror.

To understand how images are formed under a variety of situations using a concave mirror, refer to figures 4-12 through 4-16. Then study figure 4-20. It should soon be obvious that a concave mirror affects light rays just like a positive lens.

To understand the images formed by concave mirrors illustrated in figure 4-20, first review figure 3-6, which shows how to compare objects and their corresponding images.

Concave mirrors will form real images under most circumstances, but you must remember we are dealing with reflected light rather than refracted light. Therefore, when an object is located beyond the center of curvature of a concave mirror, the image attitudes will be real, inverted, normal, and diminished (fig. 4-20B). As the object moves closer to the mirror, the image size increases but image attitude remains the same.

When the object is located at the focal point (fig. 4-20E), no image is formed because the reflected light is parallel.

With the object located between the focal point and the mirror surface, the image will be virtual, erect, reverted, and enlarged.

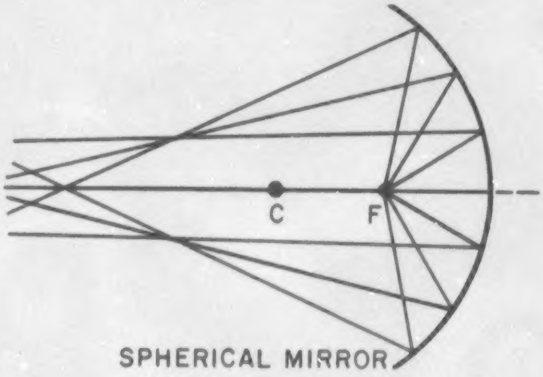
Concave spherical mirrors are used in reflecting telescopes which will be explained in chapter 5. They are also used as reflectors for most external automobile lights and flashlights.

Parabolic Reflectors

The image formations illustrated in figure 4-20 represent ideal situations which seldom exist.

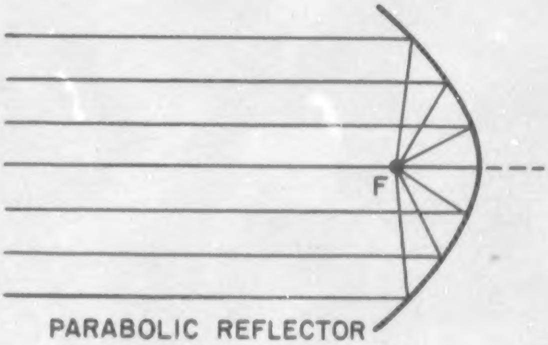
If a very small luminous source is located at the principal point of focus of a concave spherical mirror, light rays are almost parallel after they reflect from a mirror–provided the curvature of the mirror is very slight. The rays actually have a slight convergence, particularly those reflected near the edges of the mirror (fig. 4-21). For this reason, a parabolic mirror is used whenever parallel reflected rays are desired.

Study figure 4-22. A parabolic mirror is a concave mirror with the form of a special geometrical surface–a paraboloid of revolution. Light rays which emanate from a small source at the focal point of a parabolic mirror are parallel after they reflect from its surface.



137.553

Figure 4-21.–Convergence of light rays produced by a point source of light.



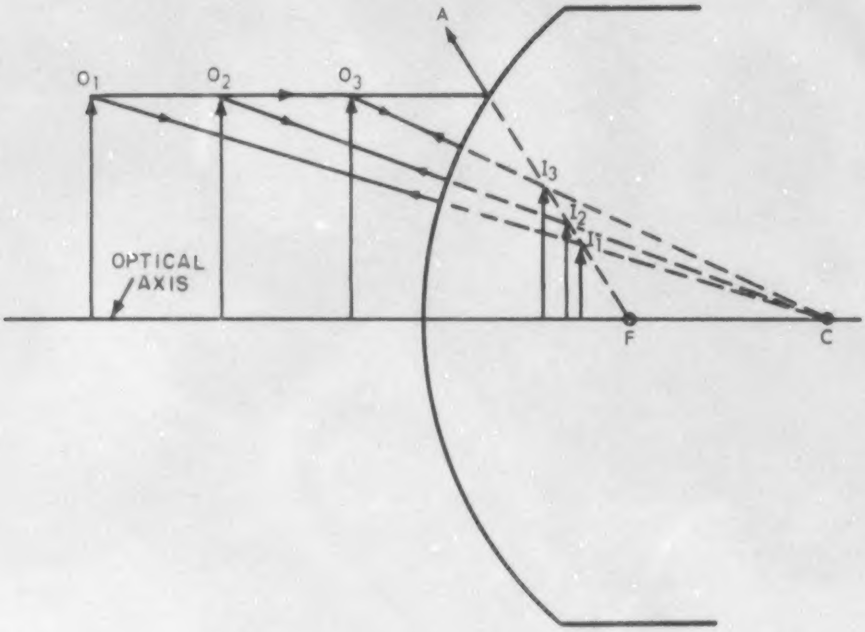
137.554

Figure 4-22.–Parallel light produced by a point source.

The source of light (usually a filament or arc) is located in the principal point of focus, and the rays diverge. All rays that strike the parabolic mirror (except those which are diffused or scattered) reflect from the mirror nearly parallel with each other, thereby providing for the formation of a powerful beam of light which diverges only slightly.

Convex Mirror

Study figure 4-23, which shows three objects (arrows O_1, O_2, and O_3) of the same size but of



137.68

Figure 4-23.—Image formation by a convex mirror.

different distances from a convex spherical mirror. The ray of light which passes along the tips of the three arrows strikes the mirror and is reflected in the manner indicated by arrow AF. The dotted extension of this line behind the mirror contacts the optical axis at the focal point.

Rays of light from the three arrowheads to the center of curvature locate the virtual image positions produced by the three arrows. Object O_1 creates I_1, and so forth. Note that the size of the image is larger when the object which formed it is moved nearer to the mirror, but an image can never become as large as its object.

As you can see, these images are virtual, reverted, erect, reduced in size, and located behind the mirror between the principal focus and the surface.

The radius of curvature of a convex mirror is negative and the image is always virtual. The focal length (F) and the image distance (D_i) are therefore negative quantities.

LENS FORMULAS

So far in this chapter, we have been concerned primarily with describing lenses and spherical mirrors and how they form images. At this point, we will discuss the formulas that are used to determine focal length, magnification, image size, image distance, object size, object distance, magnifying power, dioptric strength, and relative aperture.

FOCAL LENGTH

We have previously discussed a way to approximate the focal length of a convergent lens by measuring the distance from the lens to the real image formed with an object at infinity. The relationship between the image and the focal length of a lens is expressed in a formula called the lens law.

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$$

F = focal length

D_o = Distance of object

D_i = Distance of image

If you have a lens with a focal length of 4 inches and the object is at infinity (∞), you would substitute in the following manner. NOTE: when the distance of the object is infinity (∞), $\frac{1}{D_o}$ is considered as 0.

$$\frac{1}{4} = 0 + \frac{1}{D_i}$$

$$D_i = 4 \text{ in.}$$

Thus, you have just proven that with an object at infinity the focal length of the lens is the same as the image distance.

Calculating Image Position

Now use the lens formula to calculate the positions of the image in figure 4-12. Assume that F = 2 inches, D_o = 5 inches and substitute in the lens law.

$$\frac{1}{2} = \frac{1}{5} + \frac{1}{D_i}$$

$$5D_i = 2D + 10$$

$$3D_i = 10$$

$$D_i = 3.33 \text{ in.}$$

Now try the formula on a situation like figure 4-16. Remember, the image is formed on the same side of the lens as the object, therefore, the image distance (D_i) will be negative. Substitute your own numbers for F and D_o and see what happens.

When you work with a negative lens (fig. 4-17), you must deal with two negative quantities. The focal length (F) is negative since it is on the same side of the lens as the object; likewise, the image distance (D_i), is negative. Given an object (D_o) of 2 inches and a focal length of -2 inches, find D_i.

$$\frac{1}{-2} = \frac{1}{2} + \frac{1}{D_i}$$

$$D_i = -D_i - 2$$

$$2D_i = -2$$

$$D_i = -1$$

The image distance for arrow O_2 in figure 4-17 is -1 in.

The lens law formula will work for any lens or mirror, positive or negative, as long as you know two of the three terms of the formula. You also must remember under which conditions the focal length and image distance are negative to obtain a correct solution. When your figures are correct, you determine image distance to be a negative quantity, the image is virtual. (See the two previous examples).

MAGNIFICATION

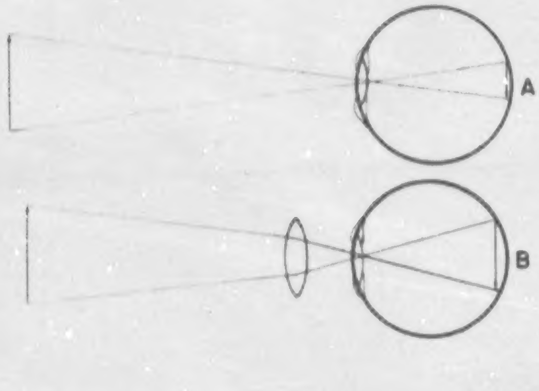
Magnification is the apparent enlargement of an object by an optical element. You can more easily understand magnification if you consider a single positive lens used as a simple magnifier.

A positive lens works as a magnifier because it makes the light rays subtend a larger angle at your eye than is possible with the unaided eye. Figure 4-24 illustrates an object viewed by an unaided eye (A), and an object viewed through a magnifier (B).

The amount of magnification apparent in dealing with lenses or mirrors depends on image and object size and image and object distance. The formula is expressed as:

$$M = \frac{S_i}{S_o} \text{ or } M = \frac{D_i}{D_o}$$

To understand the lens law formula and the formulas dealing with magnification, you can actually draw the examples presented next. If your drawings are accurate and if you use the principal rays dealing with image formation



137.502
Figure 4-24.—Object viewed with the unaided eye and through a magnifier.

properly (fig. 4-11), you can prove that the formula works.

Draw a convergent lens that is 3 inches high and use dotted lines to show the optical axis and the principal plane. Next, measure off 2 inches along the axis on each side of the optical center and mark them with the letter "F" to remind you that they are the focal points. Now, draw an arrow 1 inch high with its tail on the optical axis and placed 3 inches to the left of the principal plane.

To find the image of the arrowhead, draw a ray from the arrowhead to the principal plane of the lens, and make the ray parallel to the optical axis. What do we know about rays parallel to the optical axis? We know that they bend as they pass through the lens, and after they leave the lens they pass through the principal focal point on the other side. From the point where your first ray meets the principal plane, it will pass through the second focal point. So add that refracted ray to your drawing. We know that the image of the arrowhead is somewhere along that ray.

Now, for your other ray use the one that passes through the first focal point. Draw a ray from the arrowhead through the first focal point, and continue the ray until it meets the principal plane of the lens. (If this line goes below the lens you have drawn, don't worry about it. This plotting method will work anyway. Just continue the line that represents the principal plane until it meets the ray.) What do we know about rays passing through the focal point? We know that they bend when they pass through the lens, and that they emerge parallel to the axis. So, from the point where your second ray meets the principal plane, draw the refracted ray on the right side of the lens, and make it parallel to its optical axis. The image of the arrowhead is at the point where that ray crosses the first one you drew.

There is another ray you can plot, if you want to. Any ray passing through the optical center of the lens will be refracted at each surface (unless the ray is traveling along the axis). But the two refractions will be equal, and they will be in opposite directions. For a ray passing through the optical center, the total deviation is zero. When plotting images, you can draw any ray that passes through the optical center of a lens as if it went through the lens in a straight line. Now, add this third ray to your drawing: Draw a line from the arrowhead to the optical center, and continue it in a straight line on the other side of the lens. If you have made your drawing carefully, all three rays will meet at the image point.

You have found the image of the arrowhead. You know, of course, that the image of the tail is on the optical axis, because rays traveling along the axis are not refracted. Since the arrow is at a right angle to the axis, the image will be at a right angle to the axis, too. So, draw a line from the image of the arrowhead to the axis, and there is your image of the arrow. Your drawing should look like figure 4-14.

If you have made the drawing carefully, you can use it to check the formulas for image size and distance. In the drawing, you have an object 1 inch high, 3 inches from a lens of 2-inch focal length. Use the lens law to find the image distance. The formula is:

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$$

$$\frac{1}{2} = \frac{1}{3} + \frac{1}{D_i}$$

$$3D_i = 2D_i + 6$$

$$D_i = 6$$

In the drawing, the image should be 6 inches from the lens. Measure to see if it is. Hold the ruler on the optical axis, or parallel to the axis, and measure the distance from the image to the principal plane of the lens. The more careful your drawing, the closer the distance will be to 6 inches.

Now use the same drawing to check the formulas for magnification. The formula is:

$$M = \frac{D_i}{D_o}$$

substitute

$$\frac{6}{3}$$

$$M = 2$$

The image is twice the size of the object.

Now use the other formula for magnification.

$$M = \frac{S_i}{S_o}$$

substitute $2 = \frac{S_i}{1}$

$$S_i = 2$$

Again, the image is proved to be twice the size of the object. Therefore, the magnification is 2.

Now, try it again. Use the same focal length, 2 inches, but this time put the arrow 4 inches to the left of the principal plane. This time make the arrow 2 inches long. To locate the image, find the point that is the image of the arrowhead, and then find the point that is the image of the tail. When you connect the two, there is the image of your arrow. Remember, for each point there are three different rays you can plot. Any two of them will locate the image. Use whichever two rays are most convenient for you. When you have finished your drawing, it should look something like figure 4-13.

Use the lens law formula to determine image distance, then use the two formulas for magnification. If your work is correct, the image is the same size as the object. Consequently, the magnification is 1.

The formulas for magnification will work for any situation dealing with image formation, even negative lenses or concave mirrors. All you have to do is remember which situations involve negative focal length or image distance.

Just for practice, construct some examples like figures 4-12, 4-16, and 4-17, and solve for magnification.

So far, we have talked about objects a short distance outside the focal point of the lens. Before going on, let us work out a more practical problem. Suppose you are looking at a ship through a telescope. The objective lens of your telescope (the one in front–the one nearest the object) is a convergent lens. Assume that the objective lens has a focal length of 10 inches and that the ship you are looking at is 200 yards long and is 5,000 yards from your telescope. Then how far from the objective lens of the telescope is the image of the ship? And how long is the image? Before you can substitute in the formula, you must get all the distances in the same units. Since you want the answer to be in inches, you must convert the other units into inches. The ship is 200 X 36 inches long, or 7,200 inches long. Its range is 5,000 X 36, or 170,000 inches. Now use the lens law.

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$$

substitute $\frac{1}{10} = \frac{1}{180{,}000} + \frac{1}{D_i}$

solve for D_i

$$18{,}000\ D_i = D_i + 180{,}000$$

$$17{,}999\ D_i = 180{,}000$$

$$D_i = 10.0005 \text{ in.}$$

The distance of the image is just a trifle over 10 inches. And the focal length of the lens is 10 inches. So you can see that the image of a distant object is practically in the principal focal plane.

What about the size of the image? You know the object is 7,200 inches long, so you can use the formulas for magnification to determine the size of the image.

$$M = \frac{D_i}{D_o} \text{ or } \frac{S_i}{S_o}$$

therefore $\frac{D_i}{D_o} = \frac{S_i}{S_o}$

substitute $\frac{10}{180{,}000} = \frac{S_i}{7{,}200}$

solve for S_i

$$180{,}000\, S_i = 72{,}000$$

$$S_i = \frac{72{,}000}{180{,}000}$$

$$S_i = .4 \text{ inches}$$

You may not believe that an image only .4 inch long is practical, but you are using a telescope, so the small image will be magnified by an eyepiece.

MAGNIFYING POWER

To understand magnifying power, first recall how an optical element affects the size of an image. As you know, image size depends on focal length, object size, and object distance. The focal length of any particular optical element is constant, but image size, depending on object distance, is variable. An image can be any size from a mere point of light up to one so large that there will not be enough light to reproduce the image distinctly.

When you want to make an object appear larger, you can either use a magnifying lens or move the object closer to your eyes. If you bring objects closer, your eyes must accommodate constantly (change refractive power) for you to clearly focus on the object. There is a limit to how close an object can be and still allow clear vision. This minimum distance is generally considered to be 10 inches and is called the distance of distinct vision.

Magnifying power is, therefore, a constant factor depending on how an object or image will appear if it is examined from a distance of 10 inches. Thus, for an optical element, the magnifying power is the PRACTICAL LIMIT OF MAGNIFICATION.

When computing the magnifying power of a lens, the formula is

$$MP = \frac{10 \text{ inches}}{fL \text{ inches}}$$

if you have a lens with 5 inch fL, the MP will be

$$MP = \frac{10}{5}$$

$$MP = 2$$

Since most lens computations use the metric system, always remember to convert 10 inches to the same metric unit used to express fL.

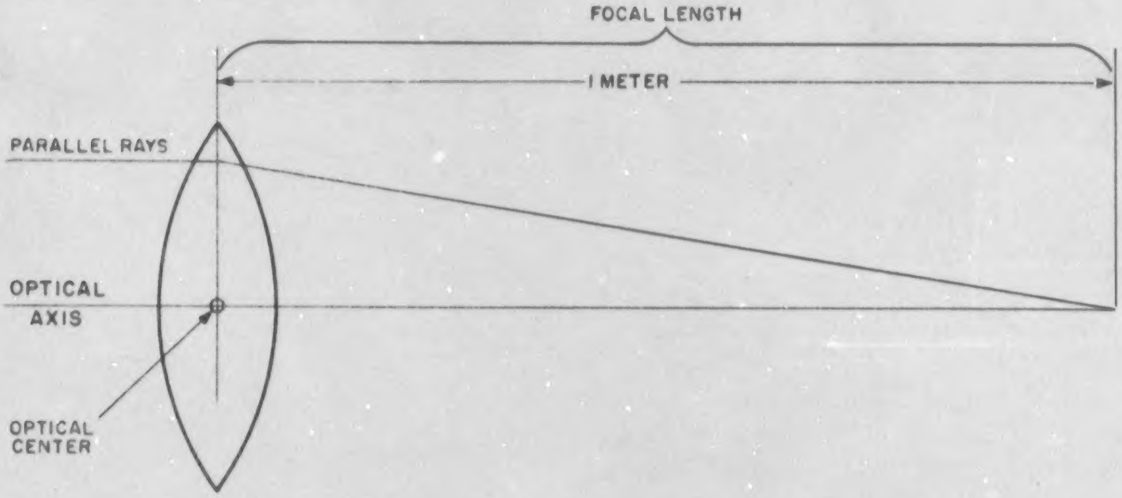
LENS DIOPTER

A lens diopter (generally called diopter) is the unit of measure of the REFRACTIVE POWER (dioptric strength) of a lens or a lens system. It is based on the metric system of measurement and is directly related to focal length.

A lens with a focal length of 1 meter has the refractive power of 1 diopter. Study figure 4-25. The refractive power of a converging lens is positive; the refractive power of a diverging lens is negative.

The refractive power of lenses, which do not have focal lengths of 1 meter, is the reciprocal of the focal lengths in meters, and it varies inversely as the focal length. This means that a converging lens with a focal length of 20 centimeters (1/5 meter) has a power of +5 diopters; whereas, a diverging lens with a focal length of 50 centimeters (1/2 meter) has a power of -2 diopters. The lens with the shortest focal length has the greatest positive or negative dioptric strength.

To find the dioptric strength of a lens with a focal length of 25 centimeters, use the following



137.86

Figure 4-25.–Lens diopter.

formula: (Remember that 25 centimeters equals .25 meters):

$$\text{Diopters} = \frac{1}{f}\text{(in meters)}$$

$$\text{Diopters} = \frac{1}{.25}\text{ meters}$$

$$\text{Diopters} = 4$$

Another formula for determining the dioptric strength of a lens when its focal length is in millimeters is:

$$\text{Dioptric strength} = \frac{1{,}000 \text{ millimeters (mm)}}{\text{F (in millimeters)}}$$

If the focal length of a lens is in inches, the formula is:

$$\text{Dioptric strength} = \frac{39.37 \text{ (or 40) inches}}{\text{F (in inches)}}$$

RELATIVE APERTURE

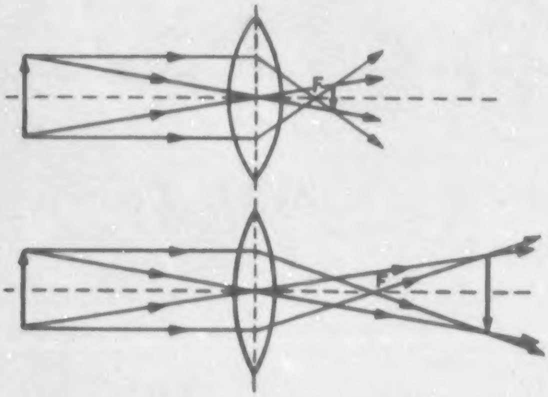
The aperture of a lens is the largest diameter through which light can enter a lens to form an image. The light-gathering ability of a lens is determined by: (1) its aperture and (2) its focal length.

Look at the lenses in figure 4-26, both of which have the same diameter but not the same focal length. The arrows on the left (the objects) have the same size, and both lenses receive the same amount of light from the objects because their apertures are equal.

The bottom lens in the illustration, however, has a longer focal length than the top lens and, therefore, makes a larger image of the arrow because the light it receives is spread over a larger area. Since the diameters of the two lenses are equal, the lens with the shorter focal length will form a brighter image than the lens with the longer focal length, because the light it receives is concentrated in a smaller area.

To find the relative aperture of a lens, divide its focal length by its diameter. For example, the formula for finding the relative aperture of a lens with a diameter of 2 inches and a focal length of 8 inches is:

$$\text{Relative aperture} = \frac{\text{F}}{\text{diameter}} = \frac{8}{2} = 4$$



137.97
Figure 4-26.—Brighter image formed by short focal length lens.

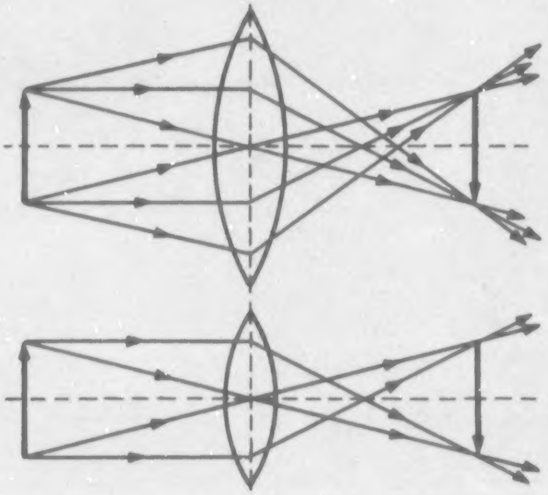
The relative aperture of this lens is therefore, generally written as f:4.

Next, study figure 4-27 which shows two lenses with the same focal length but different diameters. The larger lens at the top forms a brighter image of the object because it has a greater aperture than the bottom lens and receives more light from the object to form the image.

RELATIVE IMAGE BRIGHTNESS

When you compare the light-gathering ability of one lens with another, consider the relative aperture (focal length divided by diameter) of both lenses.

If you have two lenses with different relative apertures, you can tell which one will form the brighter image by using a formula. Suppose, for example, that you have two lenses with relative apertures of f:4 and f:2, respectively. If both lenses have the same diameter, the focal length of the f:4 lens is twice that of the f:2 lens (similar to fig. 4-26).



137.98
Figure 4-27.—Image brightness increased by enlarged lens aperture.

If the focal lengths of these two lenses were equal, the f:2 lens would be twice the diameter of the f:4 lens (similar to fig. 4-27).

In both examples, the f:2 lens forms the brighter image, because brightness of the image is proportional to the light-gathering ability of the lens, and the relative image brightness of two lenses is inversely proportional to the square of their relative apertures.

The relative image brightness of the two lenses just considered (f:2 and f:4) may be determined by using the formula, as follows:

$$\text{Relative image brightness} = \frac{(4)^2}{(2)^2} = \frac{16}{4} = 4$$

This means that the image formed by the f:2 lens is four times as bright as the image formed by the f:4 lens.

Suppose you want to purchase a camera and have narrowed your search down to two models. One has an f:1.9 lens; the other has a f:3.6 lens. Which camera will form the brighter image, and how much brighter will it be? Use the formula to find out.

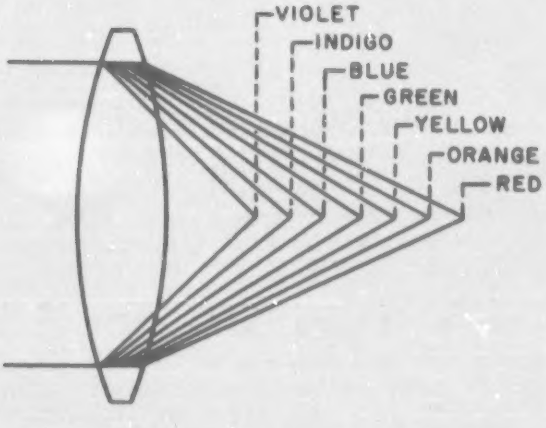
LENS ABERRATIONS

An aberration is any defect in an image produced by an optical system or individual element. For various reasons, an optical element or system cannot reproduce the true image of an object. Some aberrations are caused by errors in lens grinding or defects in the glass, others are due to the basic nature of light. The general types of aberrations are (1) chromatic, (2) spherical, (3) coma, (4) astigmatism, (5) curvature of the field, and (6) distortion.

CHROMATIC ABERRATION

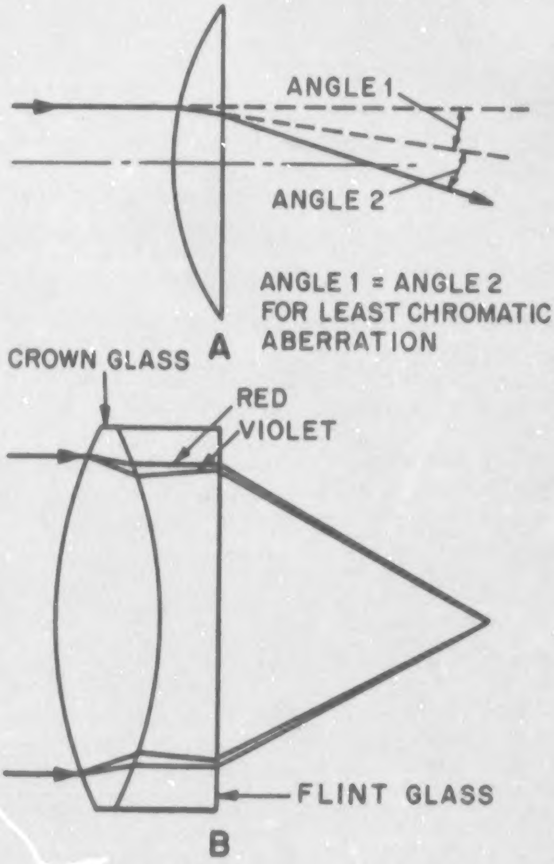
You learned in chapter 2 that when white light is refracted through a prism it disperses the light into rays of different wavelengths to form a spectrum. Dispersion also occurs in a lens when light passes through it, as shown in figure 4-28. Dispersion in a lens produces an optical defect known as chromatic aberration, which is present in every uncorrected single lens. The violet rays focus nearer to the lens than the red rays, and the other rays focus at intermediate points. The lens therefore has different focal lengths for different colors of light, and an image created by the lens is fringed with color.

Chromatic aberration may be corrected by proper spacing between lenses and also by adjusting the curvatures of the lenses. See part A of figure 4-29 which shows how a portion of the aberration can be diminished by equalizing the deviation at the two surfaces of a lens. Part B of this illustration shows how chromatic aberration in a lens can be corrected by a compound lens, one part of which is positive (convergent) and the other part of which is negative (divergent). As you learned earlier in this training course, a lens with positive dioptric strength is made of crown glass, and a lens with negative dioptric strength is made of flint glass.



137.99

Figure 4-28.—Chromatic aberration in a lens.



A. CORRECTION FOR LEAST CHROMATIC ABERRATION BY CURVATURE OF THE LENS.

B. CORRECTION FOR CHROMATIC ABERRATION BY A COMPOUND LENS.

137.101

Figure 4-29.—Correction of chromatic aberration in a lens.

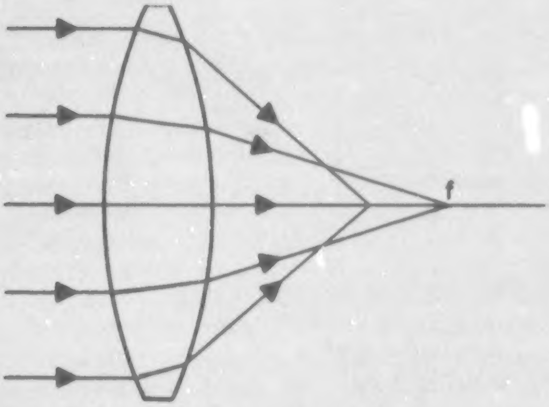
Since crown glass is more strongly convergent for blue rays than for red rays and the flint glass is more strongly divergent for blue rays than for red rays, the high color dispersion of the flint divergent lens is sufficient to compensate for the lower color dispersion of the crown convergent lens, without complete neutralization of its refractive power. Note in part B of figure 4-29 that the two rays come to a focus. A compound lens designed in this manner is called an achromatic doublet.

SPHERICAL ABERRATION

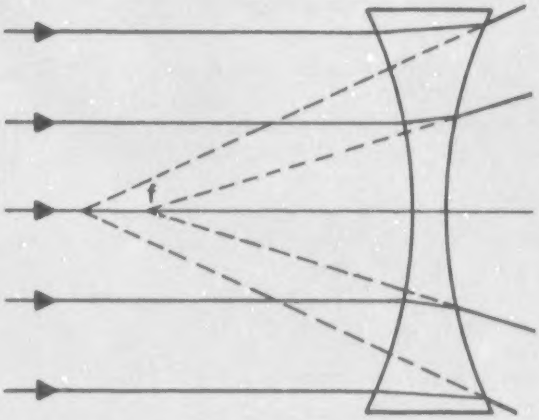
Spherical aberration is a common fault in all simple lenses. In a convergent lens, refracted light rays through its center do not intersect rays refracted through other portions of the lens at a single point on the optical axis.

The outer rays of light in figure 4-30 intersect the optical axis closer to the lens; the more central rays intersect the optical axis at a greater distance from the lens. Failure of the refracted rays passing through the lens to intersect the optical axis at a central point causes a blurred image. The image will be in focus in the center or at the edges, but a completely focused image is not possible.

Look now at figure 4-31 and note the rays of light passing through a divergent lens and the imaginary extension of the refracted rays. Intersection of outer and inner rays of light on the optical axis of this lens is opposite that of refracted rays from a convergent lens.



137.102
Figure 4-30.—Spherical aberration in a convergent lens.

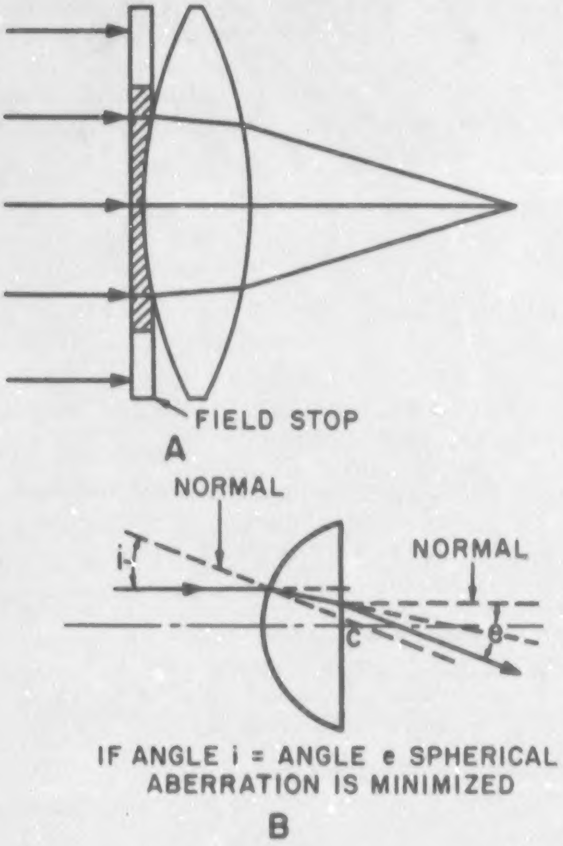


137.103
Figure 4-31.—Spherical aberration in a divergent lens.

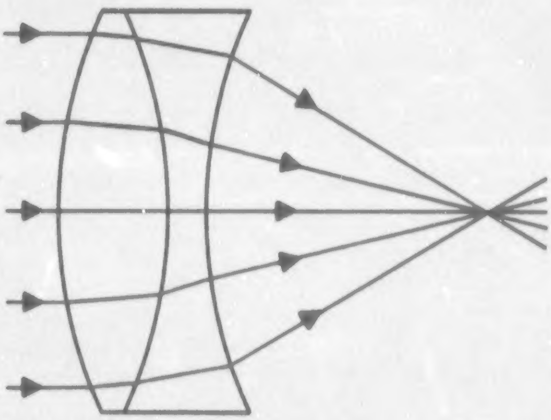
The amount of spherical aberration in either a convergent or divergent lens is influenced by (1) thickness of the lens and (2) its focal length. A thin lens with a long focal length has less aberration than a thick lens with a short focal length.

One method of reducing spherical aberration, at the expense of light intensity, is to test a lens to find out how much of the area around the optical axis (where the lens is most free of aberration) may be used to form a sharp image. Then, use a field stop to mask out all rays which pass through the lens beyond this circle (fig. 4-32A). Note the rays blocked by the field stop. The field stop is a flat ring or diaphragm made of metal (or other suitable opaque material) to mask the outer portion of the lens. The stop prevents rays from striking the lens and thus reduces the amount of light which passes through it.

Spherical aberration in a lens can also be minimized by bending the lens, which can be accomplished by increasing the curvature of one surface and decreasing the curvature of the other surface. This process retains the same focal length but reduces the amount of aberration (fig. 4-32B). In telescopes, spherical aberration is reduced by placing the greater curvature of each



137.104
Figure 4-32.—Reduction of a spherical aberration by a field lens.



137.105
Figure 4-33.—Elimination of spherical aberration by a compound lens.

lens toward the parallel rays to make the deviation of the rays at each surface nearly equal. To reduce the amount of spherical aberration to a minimum, the angle of emergence of a ray (e) must equal its angle of incidence (i). In keeping with this rule, telescope objectives are assembled with the crown side facing forward.

Spherical aberration in fire control instruments is generally eliminated by a compound lens (fig. 4-33). The concave curves of the divergent lens neutralize the spherical aberration of the convex curves of the convergent lens. Proper refractive power of the compound lens, however, is retained by selecting two single lenses with correct indices of refraction to form the compound lens. Notice that this method of eliminating spherical aberration is quite similar to the correction for chromatic aberration.

COMA

Coma is caused by unequal refracting power of concentric ring surfaces or various zones of a lens for rays of light which come from a point to a distance off the optical axis. Rays from various surfaces come to a focus at slightly different points, resulting in a lack of superimposition of the rays. Coma appears as blurring of the image for points off the optical axis.

The image of a point of light is formed by a cone of light rays refracted through a relatively wide portion of a lens. For them to form a sharply defined point of light, the rays which pass through the concentric circular zones (or rings of varying thickness of the lens) must come to a focus at exactly the same place in the focal plane.

In a lens which is producing coma, rays of light, originating at a point located off the optical axis and refracted through the inner zone, form a well-defined image of the point. Rays refracted through the next zone, however, form a larger, less well-defined image of the point which is offset slightly from the first. The image formed by each successive zone is larger, less defined, and farther removed from the initial point of light, as illustrated in part A of figure 4-34. Displacement of the successive images is in a direction toward or away from the center of the lens.

The total image of the point offset from the optical axis may be a blur in any of a wide variety of patterns—egg, pear, or comet. See part B of figure 4-34. The name "coma" comes from the resemblance of the blur of a comet.

When viewed under a microscope, a point of light influenced by coma may have a very fantastic shape as a result of the effects of all types of aberration upon it. Because coma causes portions of points of light to overlap others, the result is blurred images of objects in the portion of the field affected by coma.

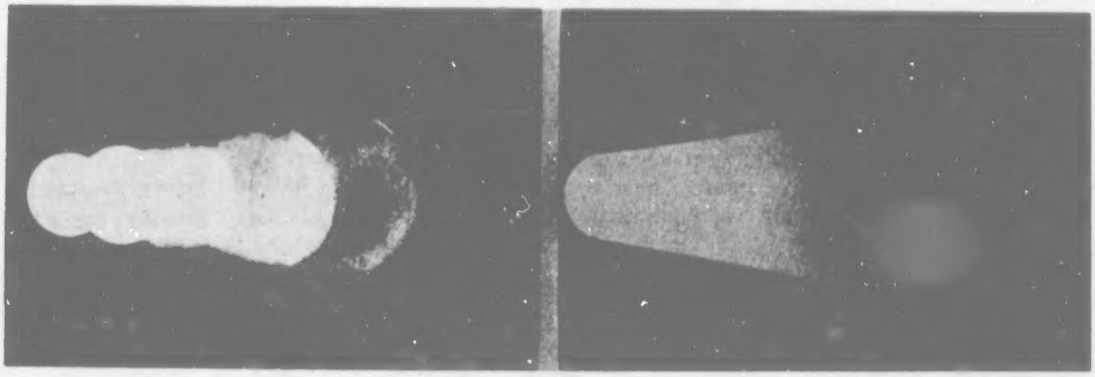
Coma can be corrected with compound lenses made of the proper type of glass for each part and with correct curves of the faces. A lens which has been corrected for chromatic and spherical aberration, plus coma, is called an APLANTIC LENS.

ASTIGMATISM

Astigmatism is a lens aberration which makes it impossible to obtain equally sharp images of lines when the lines run at angles to each other. This optical defect is found in practically all lenses except some relatively complex lenses designed to eliminate this condition.

A perfect lens will refract rays from a point of light to a sharply defined point of light on the image. Rays of light which form the image are refracted as a cone (fig. 4-35). Cross sections of these cones are circular, and successive circles become smaller and smaller until the focal point (illustrated) is reached.

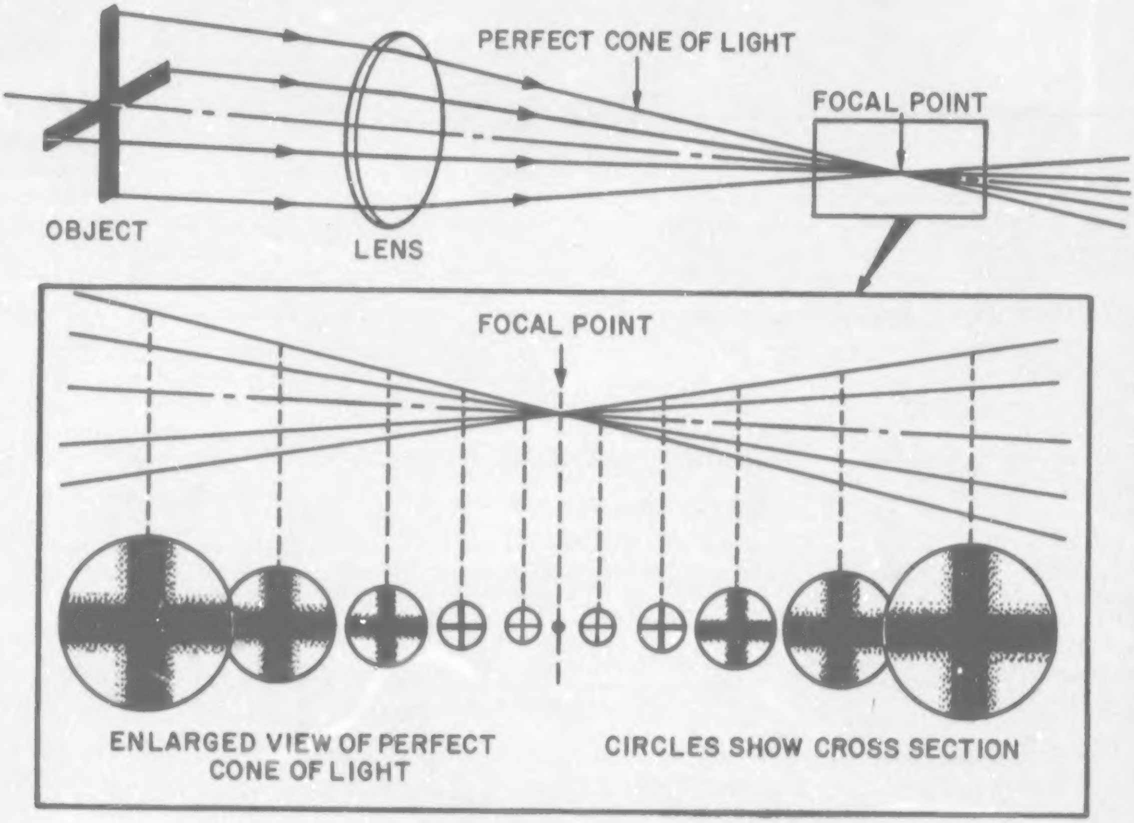
A lens with properly ground spherical or plane faces does not show astigmatism for points near the optical axis, but it will show astigmatism for points at a considerable distance from the axis because the face of the lens is then at an oblique angle to incoming light rays. The image formed by a lens which shows astigmatism converts a cone of light to an elongated oval in one plane, which compresses to a circular bundle, then becomes oval again in the opposite plane. Study figure 4-36 carefully. Between the two focal planes (horizontal and vertical) is an area known as the CIRCLE OF LEAST CONFUSION, in which plane the most satisfactory image is formed.



A. Formation
B. Appearance after formation

137.106

Figure 4-34.—Coma.


PERFECT CONE OF LIGHT
FOCAL POINT
OBJECT
LENS
FOCAL POINT
ENLARGED VIEW OF PERFECT CONE OF LIGHT
CIRCLES SHOW CROSS SECTION

137.107

Figure 4-35.—Refraction of light by a perfect lens.

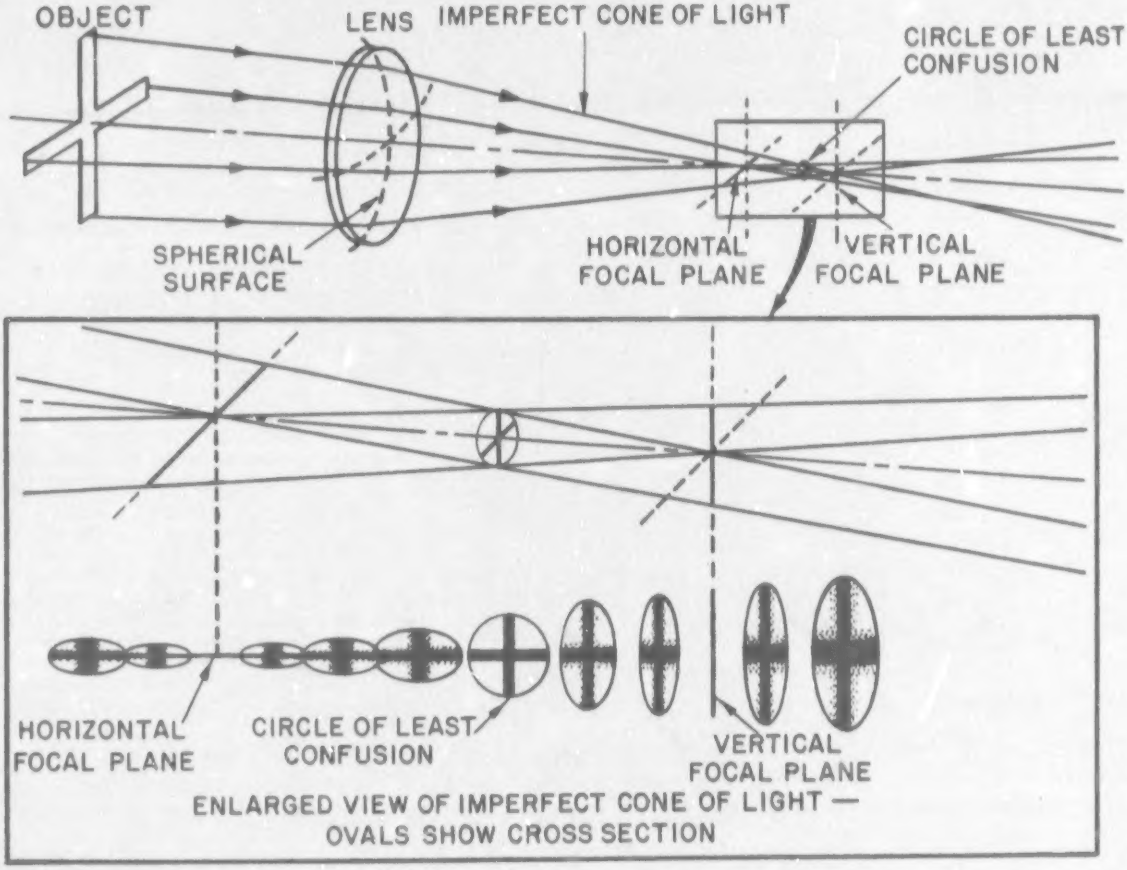
The best way to reduce astigmatism in a lens is to use a combination of several lenses in the same manner explained for eliminating spherical and chromatic aberrations. When lenses made of optical glasses with different indices of refraction are ground to different curvatures, the various types of aberration cancel each other.

A lens designer has a difficult task in his endeavors to eliminate aberration in a lens. Anything he does to correct one type of imperfection usually affects other types of aberration. He must consider many variables, including:

1. Index of refraction of different kinds of glass.
2. Difference in dispersion in various types of optical glass.
3. Curvature of refracting surfaces.
4. Thickness of lenses and distance between them.
5. Position of stops along the optical axis.

CURVATURE OF FIELD

Even in the absence of spherical aberration, coma, and astigmatism, the point images of point objects can lie on a curved surface, instead of a plane. This aberration is called curvature of field (figure 4-37). Curvature of field can be detected in an instrument or element by checking the sharpness of an image at its center and also the edges. When curvature is present,



137.108

Figure 4-36.—Astigmatic refraction of light.

the center of the image will be sharp, and the edges will be blurred. Conversely, if we adjust the element to bring the edges into sharp focus, the center will be blurred.

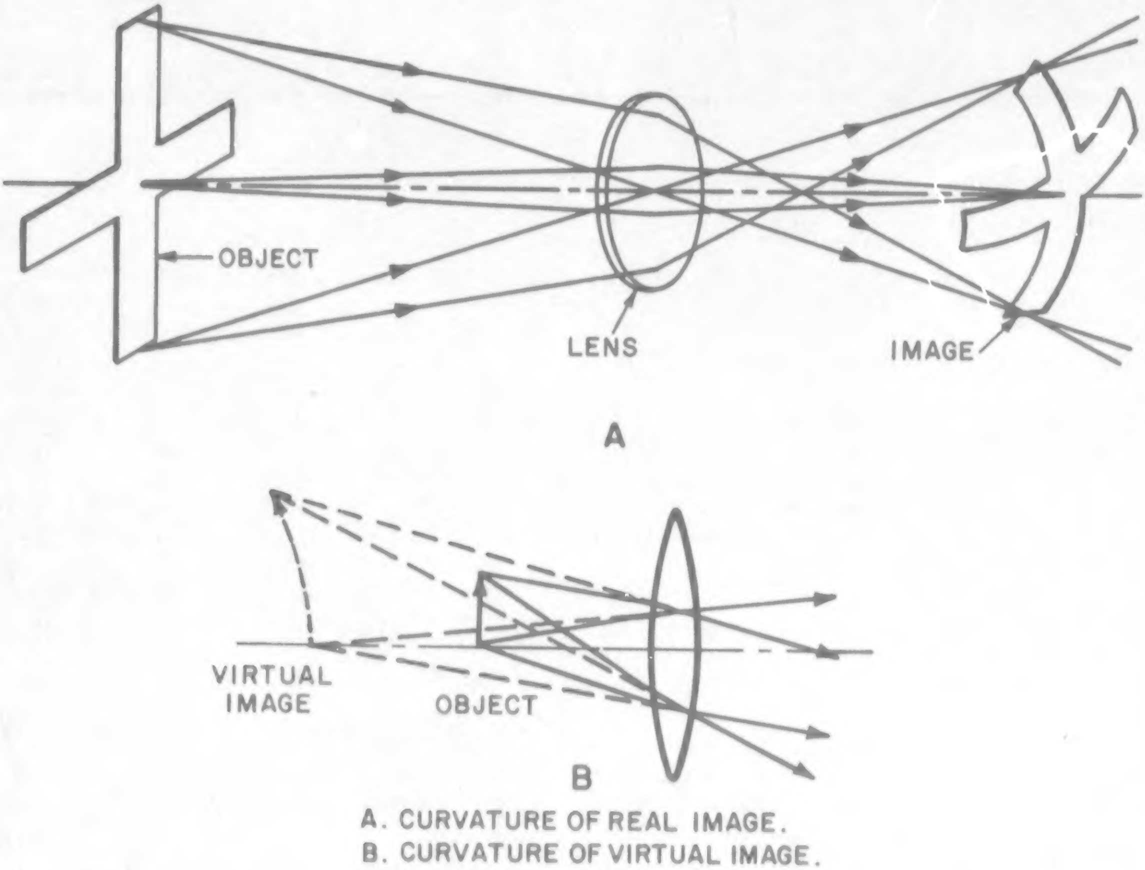
The most common method of correcting this aberration is to use a suitable combination of lenses, called field flatteners, which produce an opposite curvature of the field to cancel this defect.

DISTORTION

All of the other aberrations affect the sharpness of the image, but an image can be perfectly sharp in all respects and still be distorted. Imperfect centration or irregularity of optical surfaces produces a change in magnification from the center of the field to any other point in the field, as measured in a radial direction. Thus, objects off the optical axis will have a different magnification than objects on the optical axis.

If magnification is less for objects off the axis, you have BARREL distortion (fig. 4-38A). If magnification increases as you leave the axis, you have PIN CUSHION distortion (fig. 4-38C).

A single, thin lens will form an undistorted image, but when you must put a diaphragm in the system, you will introduce distortion. Placing the diaphragm in front of the lens will



137.111

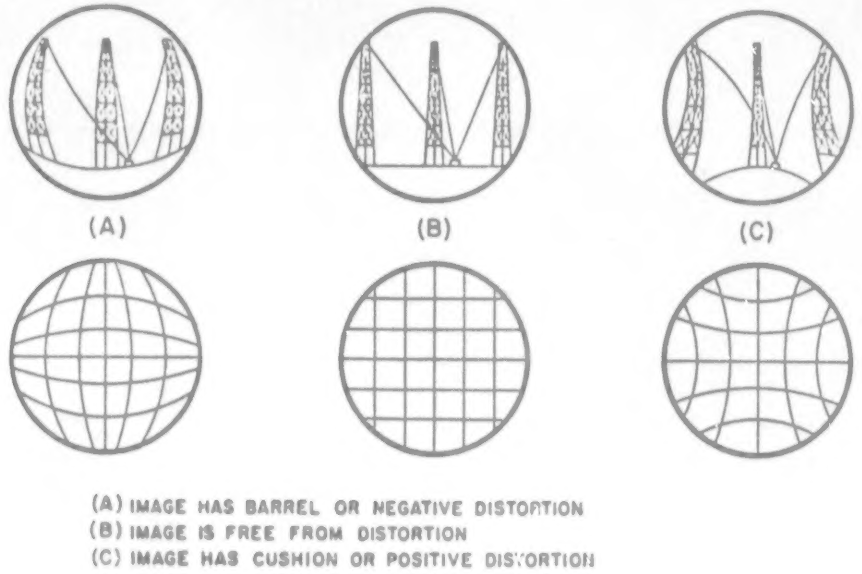
Figure 4-37.—Curvature of the image.

cause the image to have barrel distortion, and placing the diaphragm behind the lens will cause pin cushion distortion. When a diaphragm must be used in an instrument, the manufacturer will use a compound lens with the diaphragm placed between the two elements, letting the distortions cancel each other.

NEWTON'S RINGS

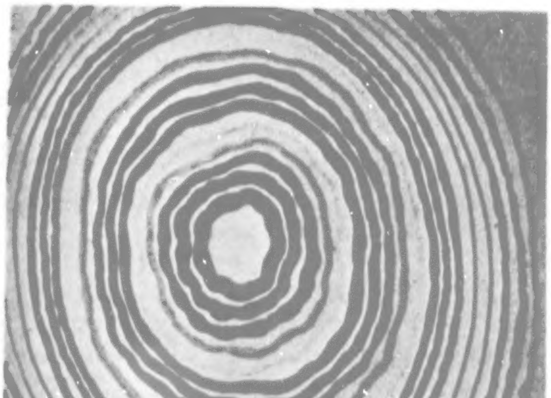
If convergent and divergent lenses of slightly unequal curvature are pressed against each other, irregular colored bands or patches of color will appear between surfaces. See figure 4-39. The pattern you see in this illustration is called Newton's rings, after Sir Isaac Newton, who first called attention to it. These rings constitute a defect in a compound lens, but the rings can be used advantageously for testing accuracy of grinding and polishing during lens manufacture.

Light waves from an object never focus perfectly at a corresponding point on an image. They form, instead, a diffused image with a central white spot surrounded by a series of concentric rings of light which fall off rapidly in intensity. This is called a DIFFRACTION PATTERN (fig. 4-40). Diffraction sets the final limit to the sharpness of the image formed by a lens, resulting from the natural spreading tendency of light waves. It occurs in images


(A)
(B)
(C)
(A) IMAGE HAS BARREL OR NEGATIVE DISTORTION
(B) IMAGE IS FREE FROM DISTORTION
(C) IMAGE HAS CUSHION OR POSITIVE DISTORTION

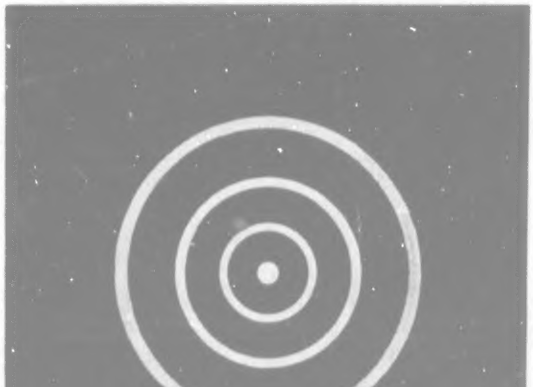
137.506

Figure 4-38.—Distorted images formed by a lens.



137.109

Figure 4-39.—Newton's rings.



137.135

Figure 4-40.—Diffraction pattern (greatly magnified).

formed by all lenses, regardless of the perfection with which they are constructed.

THICK LENSES

Thus far our discussion on lenses has dealt with thin lenses. It is now important that we explain the path of light through a thick lens.

Because light is refracted at both surfaces of a lens, all lenses have two principal planes, which were discussed earlier in this chapter. A lens is considered thick when its axial thickness is so great that the principal planes and optical center cannot be considered as coinciding at a single point on the axis.

The Navy uses three types of thick lenses:

Single thick lenses
Compound lenses
Two thin lenses combined to make a thick lens

Two equiconvex lenses are illustrated in figure 4-41. Both lenses have the same index of refraction and radius of curvature; their diameters are equal, but their thicknesses are unequal.

As you know, an A ray is any ray which passes through the optical center of a lens and emerges from the lens parallel to the incident ray without deviation. This rule applies to both thick and thin lenses. But note the difference in the A rays through the two lenses in illustration 4-41. In the thin lens in part A, the A ray is traveling toward the optical center and passes directly through without refraction or deviation.

For a ray of light to pass through a thick lens without deviation, it must travel along the optical axis, or travel as shown in part B of figure 4-41. When the ray strikes the lens, it is refracted in accordance with the laws of refraction and passes through the optical center. Upon emerging from the second surface, the ray appears to have come from the second principal point (A′) and is parallel to the incident ray, slightly offset (not deviated) from its original path.

When converging incident light strikes a thick lens, an undesirable result could occur. If the lens is thick enough, the light could converge to a focus on the second surface, or within the lens itself.

Observe that the refraction of the B rays in the two lenses in figure 4-41 is the same, but the ray in the thicker lens travels a greater distance than the ray in the thinner lens. Observe also that the principal plane (P2) of the B ray is now located to the right of the optical center of the thick lens.

Now compare the C rays of the two lenses. The refracted ray in the thin lens appears to be refracted at the same plane where the B ray refracted, but ray C of the thick lens does not appear to be refracted at the same point as the B ray—it traveled a greater distance than in the thin lens. The location of the principal plane (P1) for the C ray is to the left of the optical center. Apparent refraction, therefore, does not take place in the exact center of the thick lens as it does in thin lenses.

Because the principal planes of a thin lens coincide, we measured the focal length as the distance from the surface of the lens to the principal focus. As shown in figure 4-41, the principal planes of a thick lens do not coincide. We must consider the focal length as three separate factors: (1) front focal length; (2) equivalent focal length; and (3) back focal length.

FRONT FOCAL LENGTH

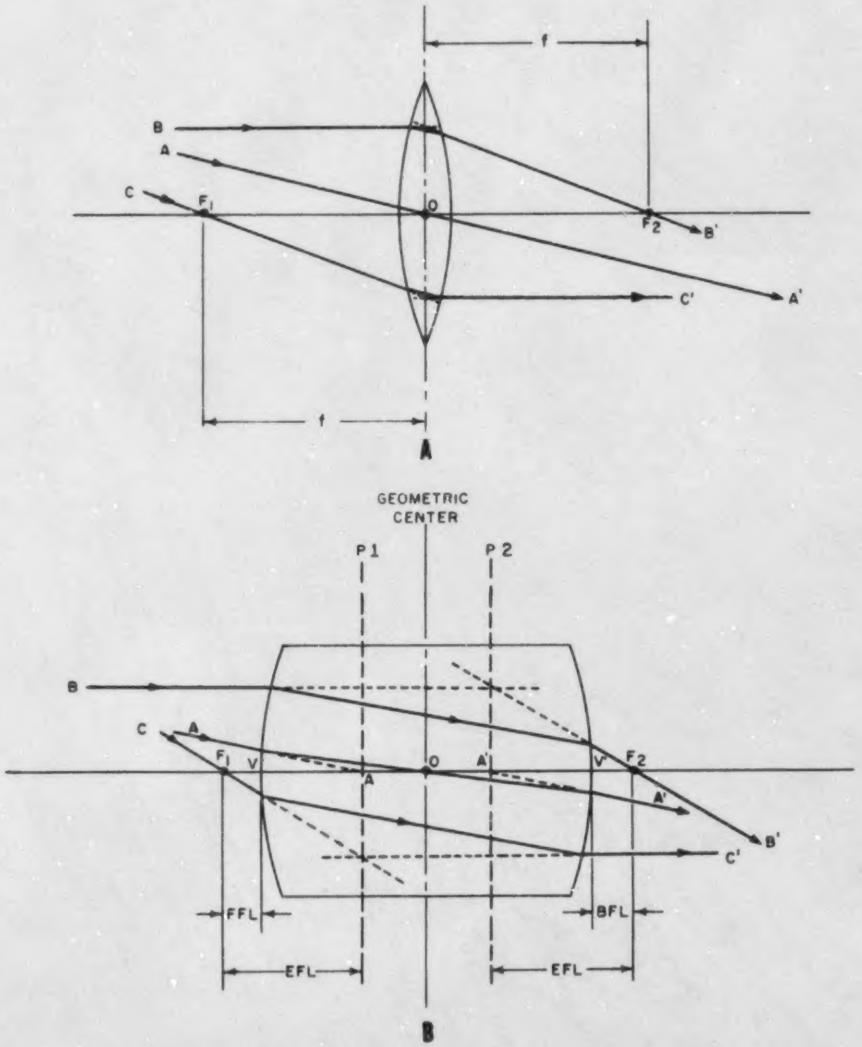
Abbreviated FFL, the distance measured from the principal focal point on the left to the vertex of the front surface is the front focal length (F1 to V in fig. 4-41).

EQUIVALENT FOCAL LENGTH

Abbreviated EFL, the distance measured from a principal plane to its corresponding principal focal point is the equivalent focal length (P1 to F1 and P2 to F2 in figure 4-41).

BACK FOCAL LENGTH

Abbreviated BFL, the distance measured from the vertex of the back surface of the lens



137.90

Figure 4-41.—A thin lens and a single thick lens.

to the focal point on the right is the back focal length (V' to F2 in fig. 4-41).

COMPOUND LENSES

Because an optically perfect lens cannot be produced as a single lens, two or more lenses made from different types of glass are frequently combined as a unit to control defects that are present in a single lens. These are called compound lenses; they will often be thick enough to be classified as a thick lens (fig. 4-42).

Two elements that are cemented together with their optical axes in alignment are called a DOUBLET. Three elements cemented together are called a TRIPLET.

Cementing the contact surfaces of lenses used in a compound lens is generally considered

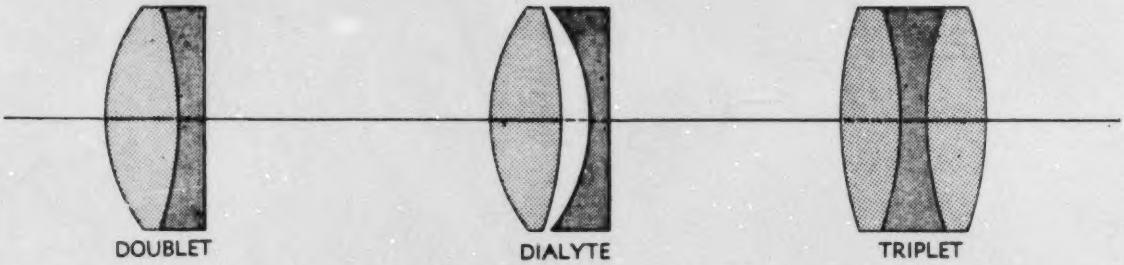


Figure 4-42.–Compound lenses.

desirable, because it helps to maintain the two elements in alignment under sharp blows, keeps out dirt, and decreases the loss of light as a result of reflection where the surfaces meet.

NOTE: The lenses of doublets too large in diameter to be cemented together (even if their inner surfaces match) form a lens combination called an AIR-SPACED or UNCEMENTED DOUBLET, commonly known as a dialyte lens.

In a dialyte compound lens, the inner surfaces of the two elements do not have the same curvature, which means they cannot be cemented together. The two lenses are separated by a thin spacer ring, or tinfoil shims, and are secured in a threaded cell or tube.

LENS COMBINATIONS

If you arrange two thin lenses in proper position, they will perform as a single thick lens. Study figure 4-43 which illustrates two symmetrical thin lenses used as a thick lens. All the laws of refraction apply here as they did in figure 4-41. The only variation in the two systems is the way you measure focal distances. Because the two lenses are very thin, the principal planes of each lens lies in the geometrical center. For this reason we measure the focal distance for each lens from the individual principal planes. The equivalent focal length is measured from the principal plane of the combination.

When thin lenses used in combination are identical in optical characteristics, FFL and BFL are equal; but if the focal length of one lens differs from that of the other, the FFL and BFL are unequal. When the thin lenses differ optically, the equivalent focal length on each side will still be equal because the EFL is calculated from the principal planes in the combination.

The formulas for computing the three focal distances are:

$$\mathrm{FFL} = \frac{(\mathrm{F1 \ X \ F2}) - (\mathrm{S \ X \ F1})}{\mathrm{F1 + F2 - S}}$$

$$\mathrm{BFL} = \frac{(\mathrm{F1 \ X \ F2}) - (\mathrm{S \ X \ F2})}{\mathrm{F1 + F2 - S}}$$

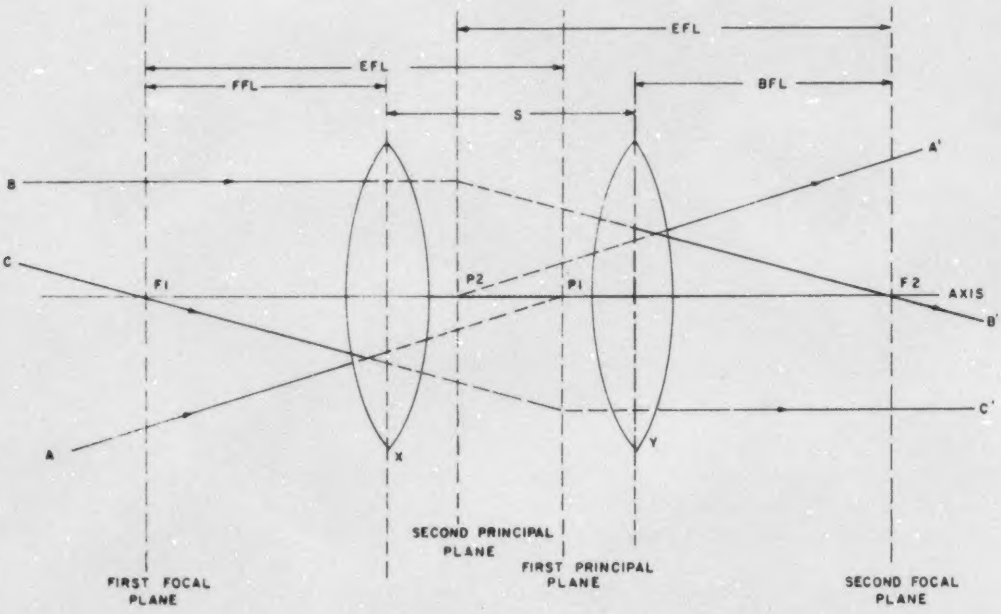
$$\mathrm{EFL} = \frac{\mathrm{F1 \ X \ F2}}{\mathrm{F1 + F2 - S}}$$

F1 = focal length of lens X (in combination)

F2 = focal length of lens Y (in combination)

S = separation of the two lenses (X & Y, or left and right) in a combination, measured from their principal planes

Refer again to figures 4-41 and 4-43. Notice how the C ray is used to establish the first principal plane (P1) and the B ray establishes the second principal plane (P2). In figure 4-43, the first principal plane is to the right of the second principal plane. This is entirely correct and quite common in two lens combinations. Remember, when you measure EFL, measure from F1 to P1 or F2 to P2. The distances will be the same



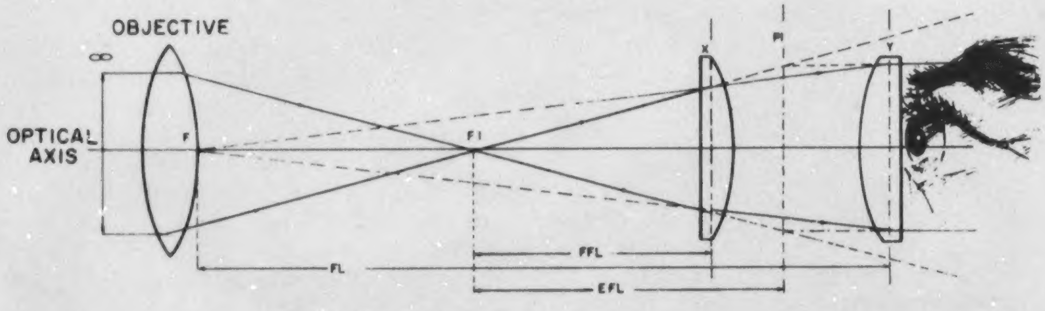
137.507

Figure 4-43.—Symmetrical thin lenses used in combination as a thick lens.

regardless of the difference between the two lenses.

Actual refraction of light rays passing through each lens in figure 4-43 is not shown. By now you should have a good idea of what happens at each lens surface. Refer to figure 4-44 which illustrates the use of two thin lenses in combination in making an eyepiece of a telescope. You will study eyepiece systems in detail in chapter 5, but the application is very appropriate at this point.

As you study the illustration, you will notice that lens X is within the focal length of lens Y, and it makes diverging rays from focal plane F1 less divergent. Also notice that the focal length of lens Y is longer than the EFL. This helps to



137.508

Figure 4-44.—Two thin lenses used as an eyepiece.

illustrate that each thin lens in a combination has a definite focal length, but, when used together, the resulting EFL of the combination is shorter than the focal length of either lens.

MISCELLANEOUS OPTICAL ELEMENTS

In addition to the optical elements you have studied thus far there are three other elements that affect light transmission in an instrument. These elements are reticles, color filters, and polaroid filters.

Reticles

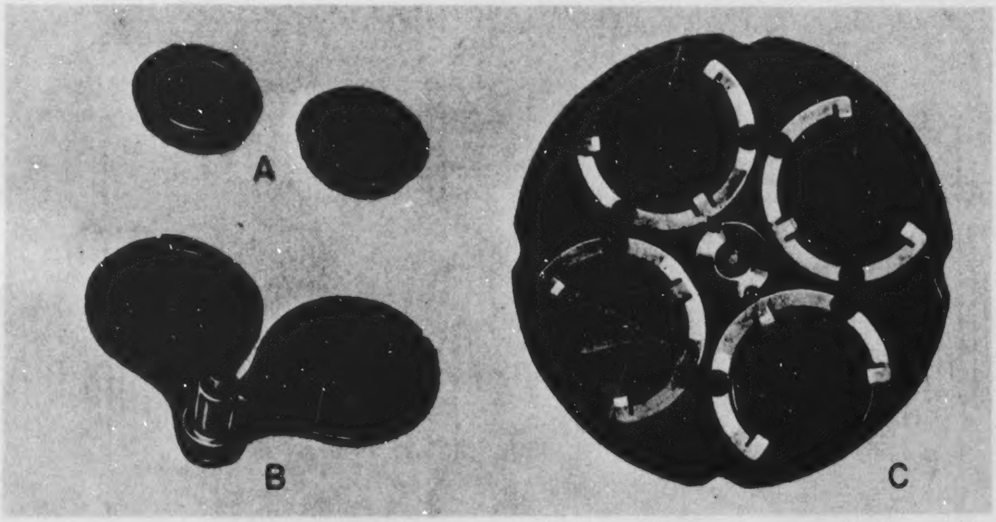
Most reticles used in optical instruments are glass disks with plane parallel surfaces on which appropriate markings are engraved or etched. In some instances, a planoconvex or planoconcave lens is necessary at the point where a reticle is generally mounted, and the markings are therefore engraved on the plano surface. The function of a reticle is to superimpose reference marks on the image of a target.

A pellicle, which is similar to a reticle, is sometimes used to superimpose a reference mark on a target image. It is usually mounted at an angle so that the main line of sight is transmitted through the pellicle while an auxiliary line of sight is reflected from it into the eye of the observer.

Colored Filters

Filters (sometimes called ray filters) are colored glass disks (with plane parallel surfaces) placed in the line of sight in optical instruments to reduce glare and light intensities. Separate elements may be attached or detached (fig. 4-45A), filters may be swung in or out of the line of sight (fig. 4-45B), or they may be mounted on a rotating disk which makes insertion and removal from the path of light easy. Figure 4-45C shows a disk with three colored and one clear filter mounted.

Some of the different types of colored filters used in optical instruments to improve visibility, are amber, blue, green, red, smoke, and yellow. Red, yellow, and amber filters are generally used under varying conditions of fog or haze to filter out the scattered blue and green light which reduce visibility if unfiltered. Red filters are used to improve contrast when a target is against



137.122

Figure 4-45.—Color filter mountings.

a blue or green background. Green, amber, and smoke filters are useful in bright sunlight or for reducing glaring reflections. Dark smoke filters reduce light intensities so much that they can be used only in the brightest sunlight or against searchlights. Blue filters absorb scattered red-yellow light, consequently they are helpful in detecting camouflaged objects.

Polaroid Filters

Polaroid filters have three useful purposes: (1) to increase image contrast; (2) to cut glaring reflections; and (3) to control the intensity of light presented to the user of an optical instrument.

To understand how they work, you need to recall the wave motion theory of light. Light radiates in all directions from a source, and the waves vibrate in all possible directions at right angles to the line of travel. You can observe this effect by visualizing a series of ropes passing through a picket fence and secured to some object on the other side of the fence. If you shake the ropes in various directions they exhibit wave motion. The fence will stop this wave motion in all the ropes except for those that are vibrating up and down. When wave motion is all in one direction, we say it is POLARIZED.

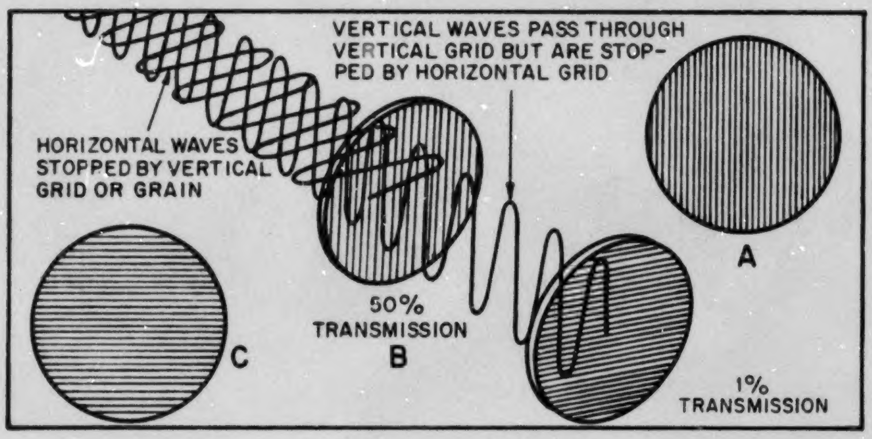
A polaroid filter is a film of plastic, either by itself or cemented between two thin glass disks. Suspended in the plastic are millions of tiny dichroic crystals of iodoquinine sulfate. (A dichroic crystal will allow transmission of light vibrating in only one direction.)

When a polaroid film is produced, the crystals are suspended in a molten plastic, and the plastic is stretched into a thin sheet as it hardens. This stretching aligns the crystals in a uniform manner so that very selective light transmission is possible.

Figure 4-46 illustrates the grid effect of crystal alignment which will polarize light. Notice in part B that the grids of two filters are at 90° to each other, which will eliminate light transmission through the second filter.

When a pair of polaroid filters are used, one remains stationary and is oriented to reduce the glare of sunlight reflecting from water. (When light reflects from any surface it is partially polarized.) The other filter can be rotated to any position desired. Therefore, you can vary light transmission through the filter from maximum (grids parallel) to minimum (grids at 90°).

Some instruments use a single polaroid filter, which can be turned to eliminate glare from various surfaces. Most military instruments now use a pair of filters to utilize the full range of capabilities.


VERTICAL WAVES PASS THROUGH VERTICAL GRID BUT ARE STOPPED BY HORIZONTAL GRID
HORIZONTAL WAVES STOPPED BY VERTICAL GRID OR GRAIN
A
50% TRANSMISSION
B
C
1% TRANSMISSION

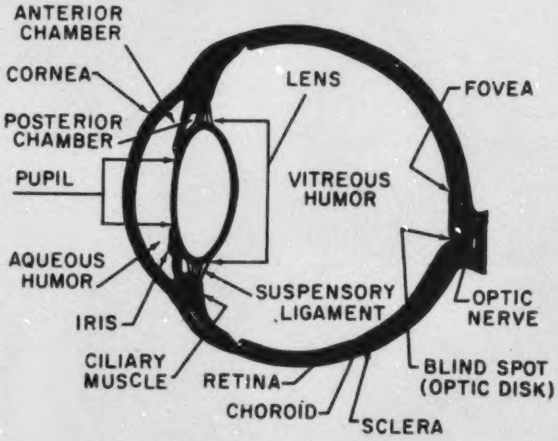
137.509

Figure 4-46.—The polarization of light.

CHAPTER 5

BASIC OPTICAL SYSTEMS

In previous chapters we discussed the formation of images through the use of various optical elements. We will now combine some of those elements into basic optical systems. An optical system as defined by MIL-STD-1241A is "a combination of optical components arranged so as to perform one or more optical functions." Of all the optical systems you will come in contact with, the most important is the HUMAN EYE; an understanding of its functions will explain more clearly the operation of optical instruments in the Navy.



137.123.1:.2

Figure 5-1.—Construction of the human eye.

THE HUMAN EYE

A complete study of the human eye involves physiological and psychological aspects, since any image formation must be interpreted by the brain. In effect the human eye is a physical image-forming and sensing system that has lenses of certain curvature and measurable indices of refraction. The eye conforms to the usual laws of image formation when producing an image on a sensitive membrane (retina) in the back of the eye (fig. 5-1). Since the retina is curved, the lens must display curvature of the field to form a useful image. Also, remember that the image formed on the retina is inverted and reverted; the brain converts this information into the erect, normal view you actually see.

EYE STRUCTURE

The human eye (fig. 5-1) is a nearly spherical organ held in shape by the sclera (tough, outer, whitish coat) and the pressure of its viscous content. The cornea, the transparent front part of the sclera, protrudes slightly as it has a greater curvature. Inside the sclera is the choroid containing blood vessels, the opaque pigment (not shown), and the ciliary process. The ciliary process includes the iris and the muscles which focus the lens of the eye. The retina covers the inside of the choroid up to the ciliary muscle. The space between the cornea and the iris is called the anterior chamber, and between the iris and the lens is a posterior chamber. Both are filled with different types of fluid. The lens is attached to the ciliary muscle by many fibers called suspensory ligaments. Except for the opening in the iris, called the pupil, the pigmentation of the sclera and iris normally makes the eye opaque. Without proper pigmentation, vision is impaired by glare from light leakage onto the retina.

IRIS FUNCTION

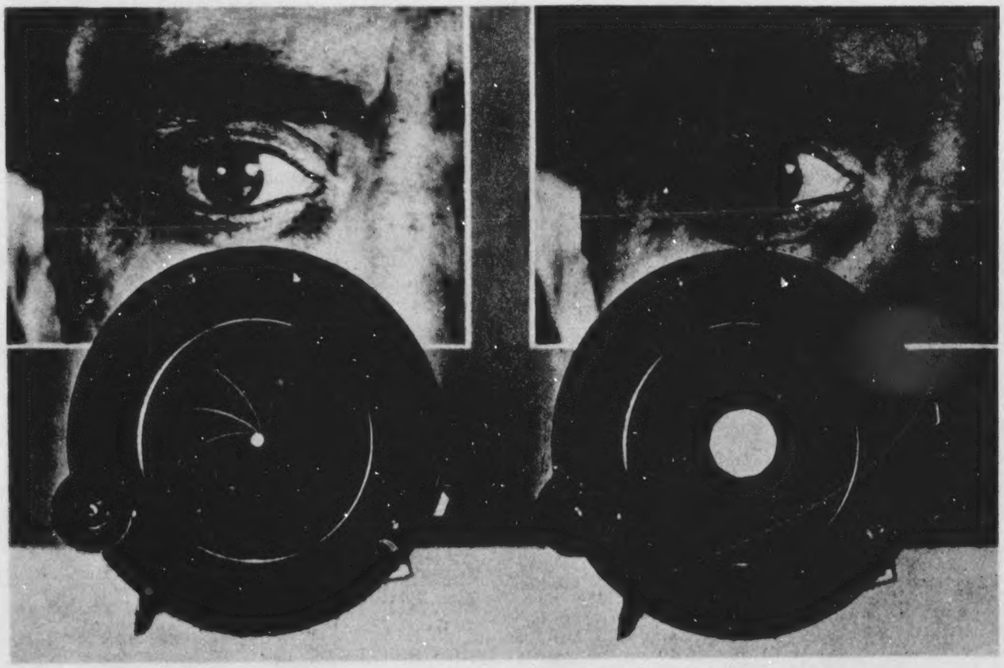
Built into this optical system named the eye, is an adjustable diaphragm (iris). It acts as an aperture stop for the lens, the same as the diaphragm of a camera (fig. 5-2). The iris opens and closes at the pupil automatically, contracting under very bright light and expanding in dim light. The size of the pupil will vary in young eyes from 8 mm in dim light to about 2 mm in bright light. The opening and closing of the iris tends to hold the illumination on the retina constant regardless of external brightness.

REFRACTING MECHANISM

The cornea and the lens act together as a convergent lens system to form a real image on the retina of the eye. The cornea (fig. 5-1) is the first refracting surface for light entering the eye and is responsible for about 75% of the refracting power of the eye. The two surfaces of the cornea usually are of similar curvatures which remain constant.

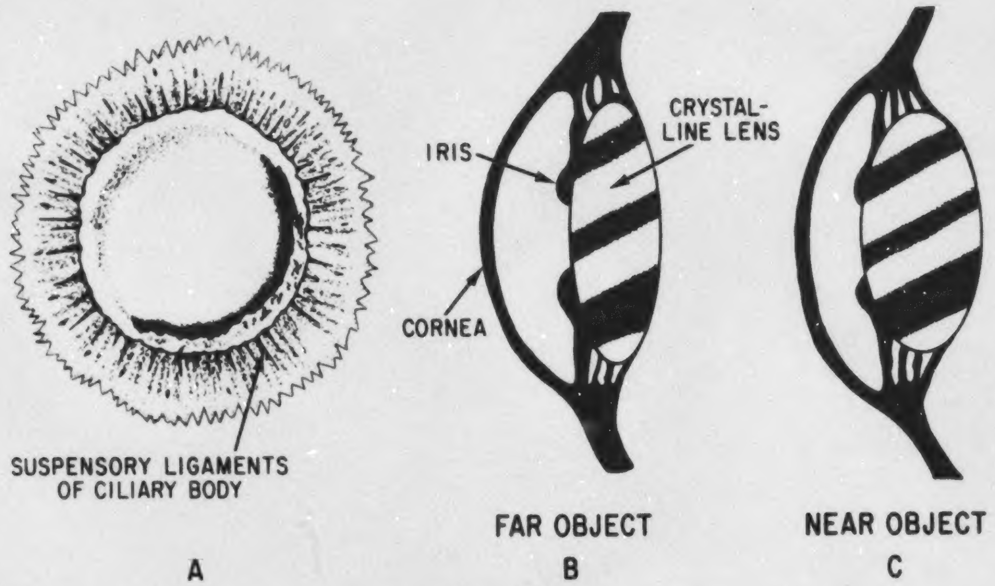
The lens is a transparent elastic body with a dense inside core and a less dense outer layer. The lens changes curvature, to focus light from near and far points onto the retina, when the ciliary muscle changes the tension of the suspensory ligaments. Figure 5-3 shows the ciliary process in detail; the eye is focused on a far object in B and on a near object in C. Notice the difference in the curvature of the two lenses. The process of changing focus from a near point to a far point is referred to as accommodation. A normal eye has the ability to focus on an object at a near point of about 5.9 inches and a far point of infinity.

As mentioned in chapter 4, the distance of distinct vision is considered to be 10 inches. Although most people can accommodate closer objects, they must strain their eyes to do so. The ability to accommodate decreases with age, as a result of loss of elasticity of the lens.



40.163

Figure 5-2.—Iris and diaphragm of a camera.



137.123

Figure 5-3.—Suspension and action of the lens.

AN OPTICAL INSTRUMENT

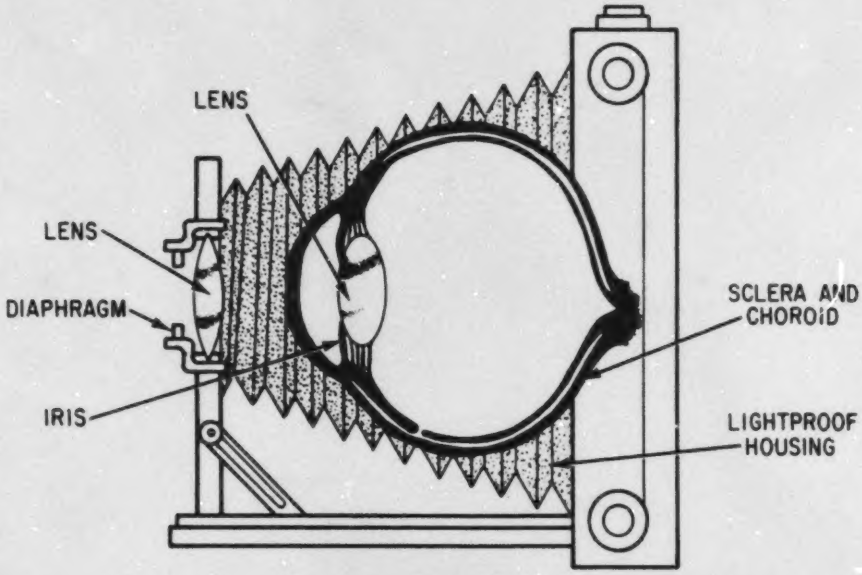
A German astronomer, Johannes Kepler, is credited with being the first man to compare the eye to an instrument like a camera. In 1604 he wrote, "Vision is brought about by pictures of the thing seen being formed on the white concave surface of the retina." The eye has been compared to the camera in numerous textbooks throughout the world. This comparison has been misleading and often has given the wrong impression of how the eye functions.

Figure 5-4 illustrates the human eye superimposed on a camera. The camera is a completely mechanical optical instrument that forms an image on sensitized film which, when processed, becomes a photograph. The formation of an image by the human eye is a physical process. After an image is formed on the retina of the eye, the process of seeing is psychological, dealing with nerve impulses and the brain. The only comparison of physical properties of the eye that can be made with the camera are lens with lens, iris with diaphragm, and sclera with lightproof housing.

VISION

Light energy striking the retina of the eye enables us to see, but the optical image formed on the retina is only the starting point of a complicated process of visual perception and visual memory. The fact is, you do not see the retinal image, the incoming light forms a pattern that provides information to the nervous system. This information is then used by the viewer to guide his movements, to anticipate events, and to construct a mental experience. The visual process is then supplemented by our memory which stores the information in the brain. The images on the retina are constantly changing in position, size, and shape as the viewer moves his eye, or the object being viewed is moved.

Usually, we are not aware of our eye movements as they are moved by the contraction of one or more pairs of opposed muscles triggered by the nervous system. Such eye movements are necessary because the area of



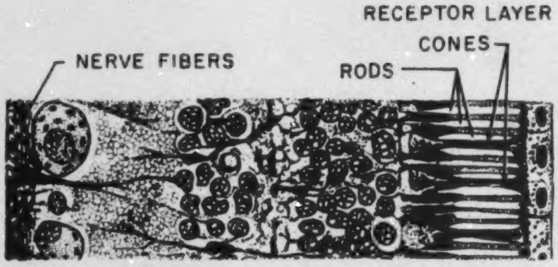
137.126

Figure 5-4.—Comparison of the eye and camera.

clear vision available to the stationary eye is severely limited. To see this for yourself, fix your eyes on a point of some some unfamiliar picture or printed page. Only a small region around the fixation point will be clear. Most of what you are viewing will be hazily visible because of the structure of the retina and the placement of its sensitive elements.

The retina, which covers most of the area behind the ciliary process, translates light energy into the nerve impulses and contains the first coordinating nerve cells in the visual system. The front part, facing the lens, is composed of blood vessels, nerve cells, nerve fibers, and connective tissues.

Figure 5-5 shows a cross section of the human retina magnified about 500 times. In this picture, light enters from the left. The light-sensitive elements are two different kinds of specially developed cells. Because of their shape, we call them RODS and CONES. The light-sensitive layer of rods and cones lies at the back of the retina. Before light can reach that layer, it must pass through several layers of tissue containing a network of nerve fibers and blood vessels. These layers are extremely thin, so they do not absorb much light. But, they do affect the sharpness of the image.



137.123.1:.2

Figure 5-5.—Section of the human retina (500X).

In some of the lower animals, the sensitive layer is at the front of the retina, with the nerve and blood supply behind it. These animals probably see more clearly than we can, but the human retina has this advantage: the sensitive layer is in contact with the rich blood supply of the choroid which helps to keep the efficiency of the retina at a high level over a long period of time.

The entrance of the optic nerve (fig. 5-1) forms a disk where there are no light sensitive cells. This is a "blind spot" where no visual sensations are stimulated. The retina thins at the fovea because there are no blood vessels or nerve fibers directly opposite the lens. Consequently, the fovea is the most sensitive area of the retina. The fovea contains only cones that are longer, thinner, and more densely packed than cones elsewhere in the retina. From here to the edge of the retina the number of cones per unit area decreases and the number of rods increases. The sensitivity of various areas of the retina to light varies, and, since the fovea is the most sensitive, it is used for fine detail and color perception. The cones of the fovea are individually connected to single nerve fibers which have a direct path into the optic nerve.

The structure of the rods and cones is complex and the exact mechanism of vision is not fully known. We do know that the retinal rods contain a red photosensitive pigment called RHODOPSIN which is bleached when exposed to light. The process of this bleaching stimulates the nerve cells in the eye, making the rods sensitive to very small amounts of light.

The retinal cones contain a violet photosensitive pigment called IODOPSIN which is similar to rhodopsin but more responsive to physical change. Even though cones respond more quickly to light than rods, it takes a greater intensity to trigger this response. An example of the change taking place in the eye is when a person goes from bright sunlight into a darkened room. It takes the eye several minutes to adjust to the lower illumination level because the retinal rods, even though more sensitive to low illumination, do not respond as quickly as the cones. The reverse procedure holds true when we again emerge from a darkened room into bright sunlight, since normal vision returns quite rapidly.

Night Vision

Cones appear to be a factor in acute vision, as the eye tends to rotate in order to bring the image nearer to the area where cones are most concentrated. It also appears that the rods in the retina are associated with night vision. Animals that hunt at night and sleep in the daytime (such as the opossum) have retinas composed almost entirely of rods. Animals that go to sleep as soon as it gets dark (most birds) have retinas composed almost entirely of cones. Human beings who get around both day and night have retinas composed of both.

Color Vision

A normal human eye can match any color with a mixture of three primary colors; red, green, and blue. The brightness of color in the objects that we see depends on the radiant energy in the light.

We know that white light is a combination of all the wavelengths of the visual spectrum and that a colored object is reflecting or emitting waves of a certain range. These different wavelengths stimulate the iodopsin in varying amounts to produce the different color sensations.

Although the cone cells are less sensitive to light than the rods, the cones are the more sensitive cells in color vision. At very low levels of illumination all radiation, regardless of wavelength, is distinguished only as varying shades of gray and black.

Color Blindness

The inability of a person to distinguish colors, that is, having only gray visual sensations, is called color blindness and is very rare in humans. More common is the condition of deficient color vision. One in 10 men and 1 in 100 women have varying degrees of color deficiencies. The most common deficiency is poor red-green discrimination; relatively rare defects are in blue-yellow vision.

With a color deficiency, one is unable to distinguish certain colors. The type of color confusion indicates the kind of irregularity. A person who has red deficiency sees red, brown, dull green, and bluish-green as the same color when they have the same brightness. A person with green deficiency confuses purplish-red, brown, olive, and green. A mild deficiency is only a small handicap and may not even be known by the person. Medium deficiency will exclude a person from working where medium color discrimination is important. Seriously deficient individuals should be excluded from all occupations which require color recognition.

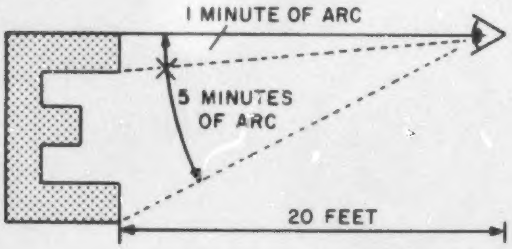
VISUAL ACUITY

The overall condition of the eye determines the degree of sharpness of vision. Printed charts, consisting of letters of different sizes are used for measuring the sharpness of vision, called visual acuity. The standard is a 5-minute square letter, the individual details of the letter subtending at the observer's eye 1 minute of arc (fig. 5-6). The reference line on the chart is normally viewed at 20 feet. Other lines on the chart have graded sizes of letters for different distances. For example, the line marked 40 feet would subtend an angle of 1/2 minute, and the line marked 10 feet would subtend an angle of 2 minutes.

Visual acuity is expressed as a fraction—the numerator is the design distance for the chart, and denominator is the line which can be read at that distance. With such a chart, 20/20 vision is normal, 20/15 is better than normal, and 20/30 is subnormal. Vision 20/30 means that the observer can read at 20 feet the line normally read at 30 feet; 20/15 vision means the observer can read at 20 feet the line normally read at 15 feet.

Resolving Power

The resolving power of the eye, or an optical system, is its ability to distinguish between two adjacent points. It is often expressed as the ability to distinguish between fine lines and small angles. Resolving power is an important property of any optical system. After all, what good would an instrument be to the Navy if we had a magnified image, but we could not distinguish any of the details in the image.



137.510

Figure 5-6.—Standard 5-minute square letter.

Figure 5-7 illustrates what is meant by two adjacent points forming an angle with the eye. The average eye can resolve details subtending 1 minute of arc; an image falls on the retina and stimulates more than one cone, with a separation of at least one unstimulated cone between them. Therefore a normal eye can distinguish between two equally bright objects, separated by an angle of only 1 minute.

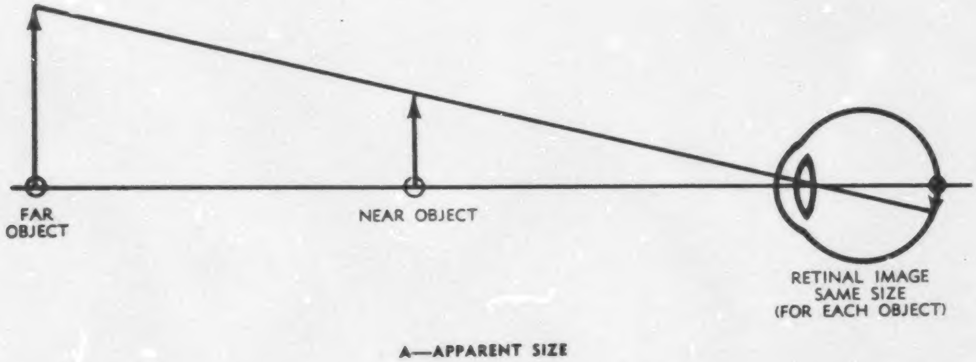
The rods and cones give the retina a mosaic structure which determines resolution. Maximum resolution depends on three factors:

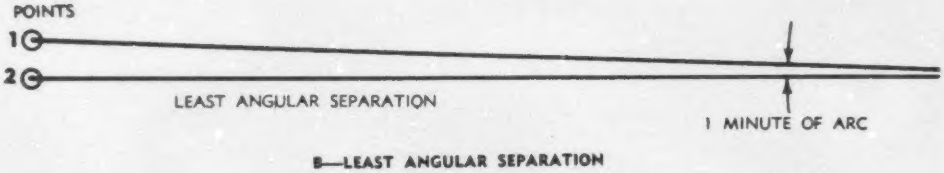
1. Retinal location of the image: The image must fall on the fovea of the retina where vision is most acute. The resolving power of the eye decreases as the image moves away from the fovea.
2. Nature of the image: Its brightness. Brightness is the light necessary to stimulate the retina. The smallness of a light or bright spot that can be seen will depend solely on its brightness.
3. Adequate time for stimulation: An image must fall on the retina long enough to cause stimulation of the nerve cells. Bright objects will stimulate quicker than dim objects.

You can fully appreciate these three factors when you look out to sea at night. If you see a small but very bright light, you have quick stimulation and the light is very noticeable. If, when looking out, you see a dim light, you must concentrate for a much longer time to discern it.

STEREOSCOPIC VISION

Having two eyes to guide us is a decided advantage in seeing, and both eyes act as a team to feed information to the brain where it is fused into a single mental image. Both eyes usually operate under the same light conditions and converge on the same object for binocular

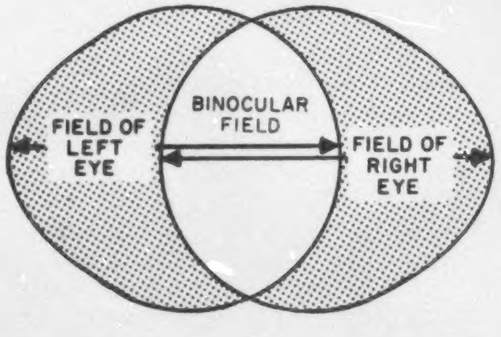




137.127

Figure 5-7.–Visual limitations.

vision. One of the advantages of two eyes, or binocular vision, is the apparent increase in brightness of about 20% above that of an object viewed with just one eye. Figure 5-8 shows the normal field of view with each eye and also the binocular field. The field of view with both eyes is normally about 160° on the horizontal and 70° on the vertical. The field includes the area seen by the left eye, the right eye, and both eyes. The binocular field exists only in the area of the field of view where the fields of the separate eyes overlap.

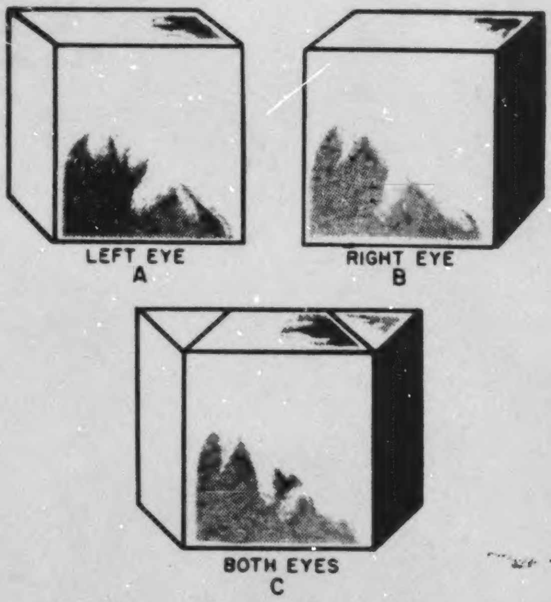


137.128

Figure 5-8.–Field of view with two eyes.

Another more important advantage of binocular vision is the experience of depth, which is called stereoscopic vision. The basis of stereoscopic vision is horizontal dissimilarity of retinal images on corresponding points of the two retinas.

Figure 5-9 shows a cube demonstrating the stereoscopic effect when you look at a near object. In studying this illustration you can see the difference in the retinal images on the two eyes. This difference is brought about by the spacing of your eyes, which allows you to see objects from slightly different angles. The spacing between the human eyes is measured from the pupil and is called INTERPUPILLARY



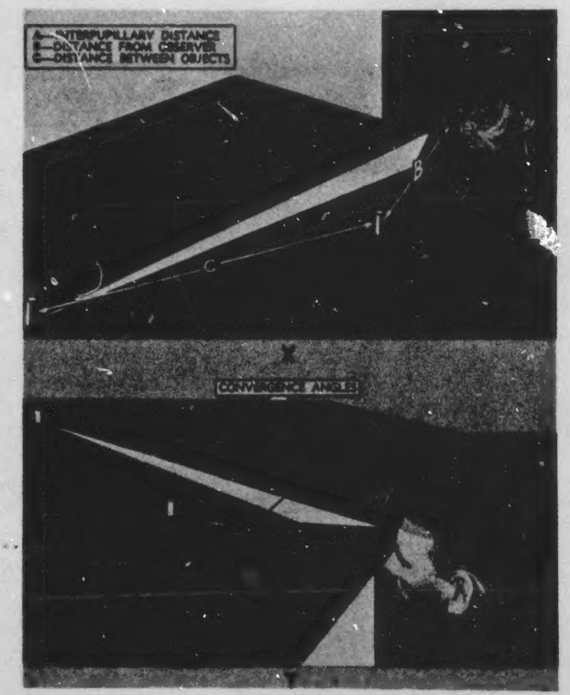
137.129

Figure 5-9.—Stereoscopic vision.

DISTANCE (IPD), normally about 64 millimeters. Stereoscopic vision can be stated as the ability to see in depth, or in three dimension. When you view an object in three dimension, you see height, width, and depth.

In a like manner, when you observe two objects simultaneously, stereoscopic vision enables you to judge the relative distance of one object from the other, in the direction AWAY FROM YOU.

Your ability to distinguish the relative position of two objects stereoscopically depends upon the interpupillary distance of your eyes, the distance of the objects from you, and their distance from each other (fig. 5-10). Other factors of depth perception being equal, the wider your interpupillary distance, the better the depth perception you secure through stereovision. For you to distinguish the position of two objects stereoscopically, the distance of the second object from the first object must be approximately equal to the distance of the first object from you.



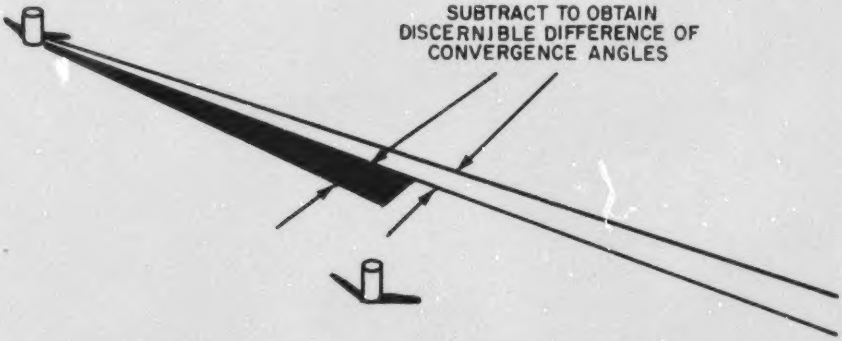
137.130

Figure 5-10.—Distinguishing the distance between two objects.

When you look at two objects and attempt to determine which is farther away, the lines of sight from both eyes converge to form angles of convergence on both objects. If the angles of convergence to both objects are identical, the objects appear to be the same distance away; but if there is a difference in the angles of convergence to the two objects, one object appears more distant than the other.

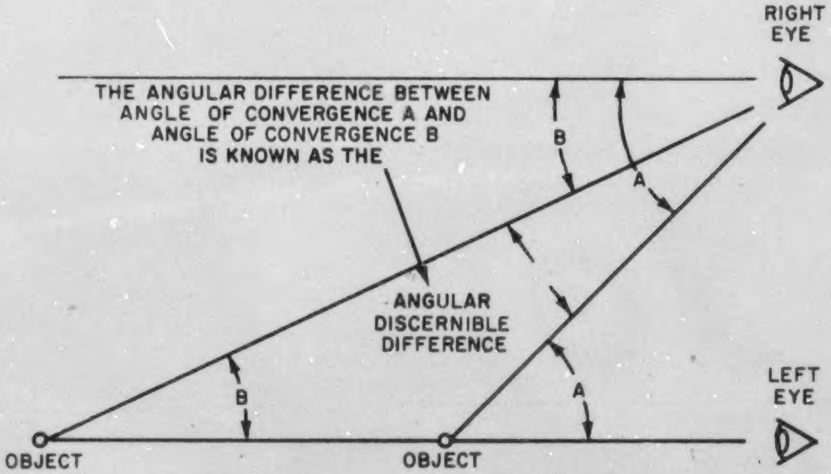
Even though the distance between angles of convergence is slight, the brain has the ability to distinguish the difference. Your ability to see stereoscopically, therefore, depends upon your capacity to discern the difference between these angles. Figure 5-11A shows the difference between the angles of convergence shown in figure 5-10.

Angles of convergence become smaller, and the difference between them becomes less



A GRAPHIC VIEW OF DIFFERENCE BETWEEN CONVERGENCE ANGLES SHOWN IN X AND Y

A



CONVERGENCE ANGLES IN STEREOSCOPIC VISION

B

137.131

Figure 5-11.—Angular discernible difference.

discernible as the objects are moved farther away from you, or as the distance between them is decreased. This difference is known as DISCERNIBLE DIFFERENCE OF CONVERGENCE ANGLE (fig. 5-11B). It is measured in fractions of minutes and seconds of arc. Stereoscopic vision for the unaided eye is effective up to only 500 yards. This distance, however, can be increased through the use of binoculars or rangefinders, which increase the interpupillary distance between the eyes and therefore increase stereoscopic vision.

STEREO ACUITY, in contrast with visual acuity, is sharpness of sight in three dimensions, or the ability to gage distance by perception of the smallest discernible differences of convergence angles. The minimum difference which you can discern between two angles of convergence is dependent upon your quality of vision, your training, and conditions which affect visibility.

A well-trained observer can discern an average difference of about 12 seconds of arc, at times, under excellent conditions of observation. This difference may be reduced to 4 seconds of arc for a series of observations. An average, untrained observer should be able to distinguish a minimum difference of 30 seconds of arc between two angles of convergence under normal visibility conditions.

ABERRATIONS OF THE EYE

The optical system of the eye suffers from some of the same aberrations as an optical system made up of glass lenses. The eye is partly corrected for spherical aberration because its refracting surface, especially the front surface of the lens, is parabolic.

The chromatic aberration in the human eye is much worse than you might think; i.e., when you look at an object, you automatically focus the green and yellow light on your retinas, but the blue light falls short of the retina, and the red light falls beyond it. If you have a divergent lens of about minus 2 diopters and a good blue light, it is very easy to demonstrate the chromatic aberration in your eyes. Just turn out all but the blue light in the room; any object appears to be wrapped in a fuzzy blue blanket. Because of the chromatic aberration in your eyes, you cannot focus the short blue rays, and the image falls short of your retinas. Now look at an object through the divergent lens and see how much clearer the object is.

The normal aberrations of the eye do not cause any significant problems in life, but there are three chief defects–astigmatism, myopia, and hyperopia–that must be corrected with eyeglasses for comfortable vision.

Astigmatism

Astigmatism in the eye is caused by a defect of the cornea whereby the surface is more strongly curved in one plane than in another. For an example, let's say that your cornea has a normal curve in the vertical plane, but is more strongly curved in the horizontal plane. You will be able to focus clearly on vertical lines, but the horizontal lines will be refracted too much and their image will fall in front of the retina.

Corrective eyeglasses for astigmatic conditions must be worn constantly for comfortable vision.

Myopia

In nearsightedness, or myopia, the image from far objects is formed in front of the retina because the refracting mechanism of the eye is too strong. Close objects, however, can be accommodated. Figure 5-12A shows how the image plane fails to fall on the retina. The defect is corrected by placing a negative lens in front of the eye as shown in figure 5-12B.

Hyperopia

Farsightedness, or hyperopia (fig. 5-13A), is caused when the refracting mechanism is too weak, and the image from close objects falls behind the retina. Distant objects can be viewed

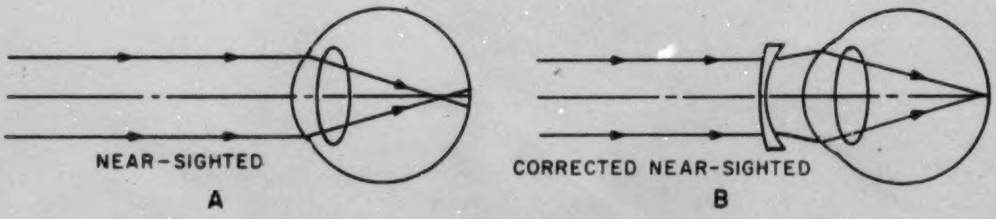
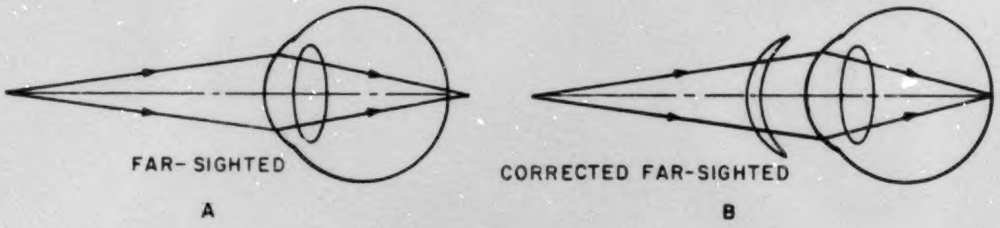


Figure 5-12.—Nearsighted vision and correction.



137.512

Figure 5-13.—Farsighted vision and correction.

normally. Hyperopia is corrected by placing, in front of the eye, a positive lens of proper strength to position the image on the retina (fig. 5-12B).

Usually, if you are nearsighted or farsighted, you will remove your eyeglasses when using an optical instrument and refocus it to correct for your eye deficiency. Focusing eyepieces should have sufficient range to take care of this defect. A range of plus 2 to minus 4 diopters will cover about 98% of eyeglass prescriptions.

Eye Strain

Eye strain or fatigue is usually caused by improper use of your eyes, or in other words, trying to make your eyes do or see something which they cannot possibly do. This problem is characterized by a tense or tired feeling, blinking, and sometimes headaches. If you concentrate too long on an interesting book, try to examine a small object by bringing it too close to your eyes, or use an improperly adjusted optical instrument, you will feel eye strain. If you must wear corrective lenses, you are all too familiar with this problem especially when you forget your glasses. The human brain tries to adjust all the muscles that control vision to force the eyes to see what it knows to be correct, putting an unnatural burden on those muscles and causing them to become tired.

You can avoid eyestrain by wearing glasses if you need them or by resting your eyes occasionally. To rest the eyes, simply look away from what you are concentrating on and glance at a distant scene or object. The eye is in its most relaxed state when looking into the distance. If you do this too often, however, people may accuse you of daydreaming.

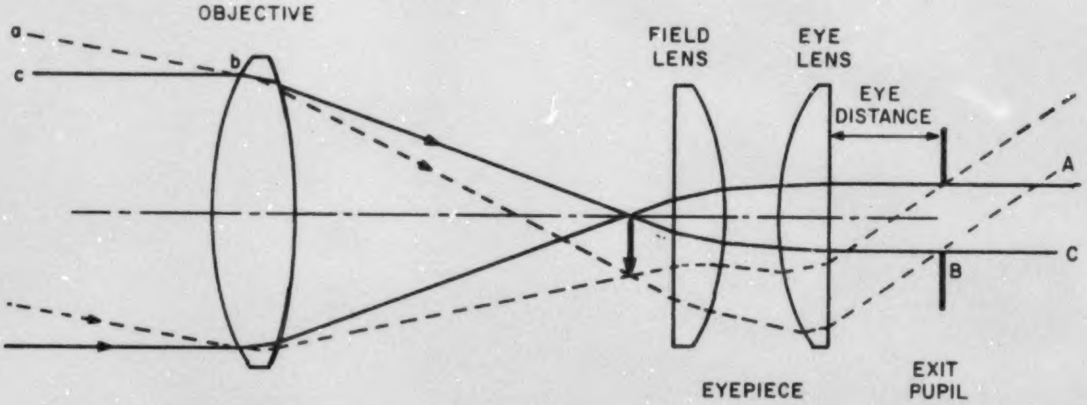
EYEPIECE SYSTEMS

As you learned in chapter 4, a positive lens forms a real image at its focal plane by converging the light rays to a focus. This image is rather small and usually too close to the eye to be clearly seen. Thus we must add extra lenses to magnify the objective image and form an image suitable for comfortable viewing. The added lens or combination of lenses is called the eyepiece system of the instrument. The eyepiece works satisfactorily if it will form a virtual image between the point of the most distinct vision of the eye (usually 10 in.) and infinity. Figure 5-14 shows the construction of a simple telescope with the eyepiece placed in a position where the focal plane of the objective and the focal plane of the eyepiece coincide.

BASIC FUNCTION

In general, the eyepiece has three basic functions in an optical instrument.

1. It must, with the objective, form a good aberration-free image of the object being viewed.
2. It must serve as a magnifier.
3. It must be designed so that the observer's eye can be placed at the exit pupil. Hence, the exit pupil must be located at least 10 to 12 mm away from the last glass surface, this being the nearest the normal eye can approach the eyepiece surface with comfort.



137.555

Figure 5-14.—Basic eyepiece function.

The objective brings nearly parallel light from a distant object to a focus, turning it into diverging rays. The eyepiece directs these diverging rays as a parallel beam into the pupil of the eye. Since most eyepieces are adjustable (focusing), the operator can focus the eyepiece to obtain a comfortable view of the image.

Magnification of the image is accomplished in the following manner: Parallel light (solid lines in fig. 5-14) enters the objective, comes to a focus, then exits the eyepiece as a parallel beam. The dotted lines represent light coming from a point on the target a distance off the optical axis. The angle of light entering the objective (abc) indicates the convergence angle presented to the unaided eye. The angle ABC represents the convergence angle increased by the eyepiece.

Optical instruments may be classified as: (1) monocular, for use by one eye or (2) binocular, for use by both eyes. Because optical instruments affect functioning of the eyes, certain adjustments must be made to the instruments to accommodate them to each eye. Most people have a dominant eye (one which is used more than the other) so the eyepiece on a monocular instrument is designed to allow the operator to use either eye.

Adjustment of a binocular optical instrument requires that the two optical systems of the unit be properly aligned with each other, conform to the interpupillary distance of the eyes of the observer, and allow for focusing of each individual eyepiece.

REMEMBER: You can sometimes bring the viewed object within focus on your retinas by accommodation of your eyes, as well as by adjusting the eyepiece of the instrument. A serious error often made by a novice is forcing the eye to focus.

When you allow your eyes to accommodate on an object before the instrument is set for proper focusing, your eyes will be under a constant strain. The correct way to focus an instrument with an adjustable eyepiece is:

1. Allow your eye to become completely relaxed by viewing a distant area.

2. Move the eyepiece to the extreme PLUS diopter position (all the way out).

3. After placing the eye in a comfortable viewing position, move the eyepiece slowly in until the image of the target is sharply defined. If you go past the point of sharp definition to a point where the image becomes blurred, DO NOT attempt to refocus from this position. Instead, back the eyepiece out again to the full PLUS position and start over.

4. When focusing an instrument, DO NOT squint your eye or in any way put a strain on its muscles. If you do, errors in setting the eyepiece will result in eye strain the entire time you are using the instrument.

Because telescopes with a magnification of 4X or less provide a sufficiently wide range of accommodation, a single-focus setting is satisfactory for most users. These telescopes have a fixed-focus eyepiece, which cannot be adjusted during operation; hence the name FIXED-FOCUS TELESCOPES, usually with a minus 3/4 to minus 1 dioptric setting.

NOMENCLATURE

Eyepieces in general use in military optical instruments may consist of one, two, or three lenses, of which, any or all may be compound lenses. The field lens is the front element of the eyepiece, and the eyelens is the rear element.

The area behind the eyelens, where the diagonal bundle of light crosses the optical axis (dotted line, fig. 5-14) establishes the EYE DISTANCE and EXIT PUPIL. Figure 5-15 illustrates the path of marginal and axial rays through two types of eyepieces.

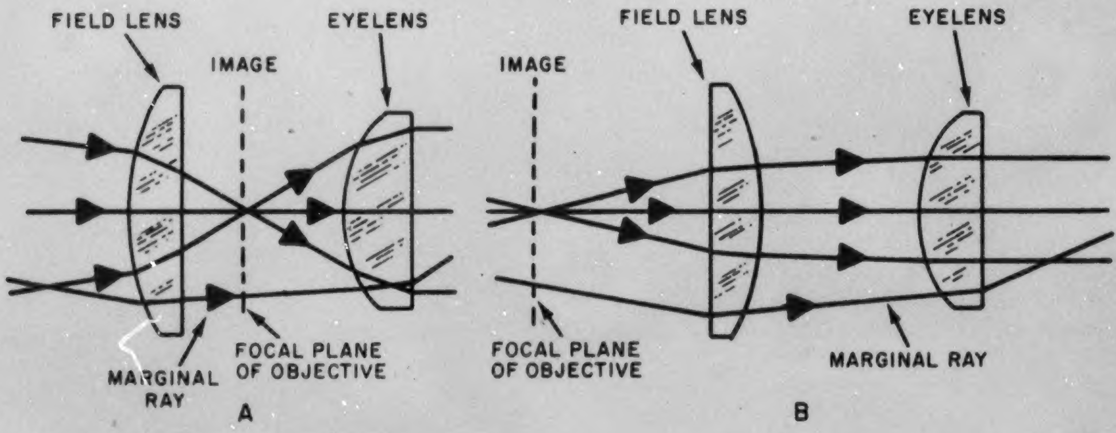
The field lens collects light from the objective image plane, which would otherwise be lost, and presents it to the eyelens. If a third element is used, it is called the intermediate or center lens, and it functions in conjunction with the field lens.

TYPES

General types of eyepieces used in optical fire control instruments will be discussed in the following paragraphs. However, you must remember that when working on an optical instrument you will often find modifications to these eyepieces. The designer of instruments will use the basic types as they are shown in this chapter, but he will often find it necessary to make some changes to produce a quality instrument. One of the prime concerns of an instrument designer is to eliminate aberrations in the instrument. The proper design and use of the eyepiece can be very useful in this function and will be discussed under the separate types of eyepieces.

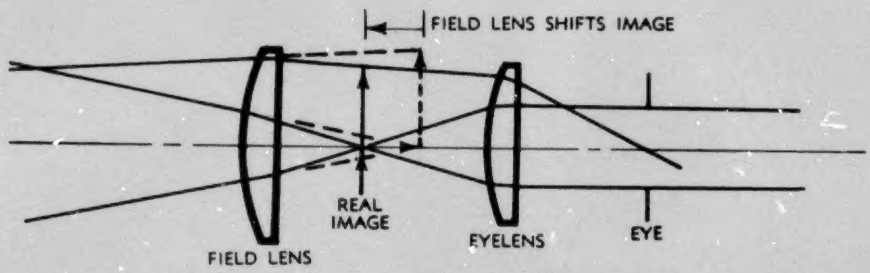
Huygens

The Huygens eyepiece (fig. 5-16) is made of two single lenses. (Usually they are both convexo-piano, and both are made of crown glass.) The diagram shows three rays converging toward a real image. The field lens deviates these



137.137

Figure 5-15.—Path of light through eyepiece lenses.



137.141

Figure 5-16.—Huygenian eyepiece.

rays slightly and sends them toward the eyepiece. You can see that without the field lens, some rays will miss the eyelens entirely. The field lens ensures that all the light passing through the system will be used to form the final image.

The Huygens eyepiece minimizes chromatic aberration, in a way we mentioned in an earlier chapter, by making the distance between the two lenses equal to half the sum of their focal lengths. The Huygens eyepiece has some spherical aberration, but it is not very noticeable at relative apertures less than about f:7. If you want to use it at an aperture greater than f:7, you must overcorrect the objective to compensate for the spherical aberration of the eyepiece.

The Huygens eyepiece can be made entirely free from coma. It shows some pin-cushion distortion, which in many instruments is not objectionable. It has a NEGATIVE astigmatism which helps correct the astigmatism of the objective.

This eyepiece has one outstanding disadvantage: since the image is inside the eyepiece, you cannot use a reticle. The aberrations of the ocular as a whole are corrected, but those of the eyelens alone are not. So if you put a reticle in the image plane, its image will be distorted and show color fringes.

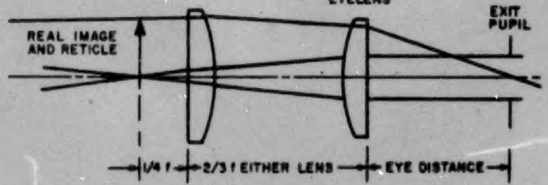
The magnifying power of the Huygens eyepiece is limited to about 10X. (If you make the focal length shorter than about 1 inch, the exit pupil is too close to the eyelens.)

Ramsden

Figure 5-17 shows the Ramsden eyepiece. It is made of two plano-convex lenses of equal focal length. The distance between them is equal to about two-thirds of that length. The arrow is the real image formed by the objective lens. As you can see, the eyepiece forms an enlarged virtual image at infinity.

The Ramsden eyepiece has one outstanding disadvantage: chromatic aberration is rather serious. It has no coma, and all the other aberrations are less than those of the Huygens eyepiece. Besides controlling all the aberrations except color, the Ramsden has another advantage over the Huygens: you can put a reticle in the image plane since the real image is outside the eyepiece.

Except for chromatic aberration, the Ramsden is a desirable eyepiece. For any given focal length, the eye distance is about 1.5 times that of the Huygens, so you can use a higher



137.138

Figure 5-17.—Ramsden eyepiece.

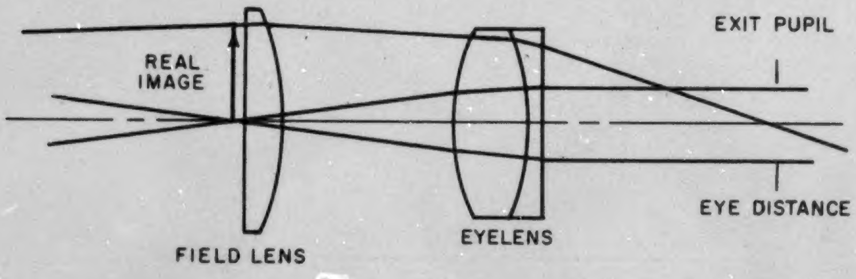
magnifying power. The aberrations of the Ramsden are increased less than those of the Huygens by slight variations in the focal length of the objective. But the only way you can eliminate the chromatic aberration is by forming the image inside the eyepiece, and then you cannot use a reticle.

Kellner

The Kellner eyepiece (fig. 5-18) is a modification of the Ramsden, the only difference being that the Kellner eyelens is a doublet. The Kellner has most of the advantages of the Ramsden and reduces the chromatic aberration. Spherical aberration is slightly greater, but distortion is less. To eliminate the chromatic aberration completely, you would have to put the field lens in the plane of the real image, but then you could not use a reticle. Most instruments that use the Kellner type eyepiece have the field lens a short distance beyond the image plane. They sacrifice a part of the color correction in order to use a reticle.

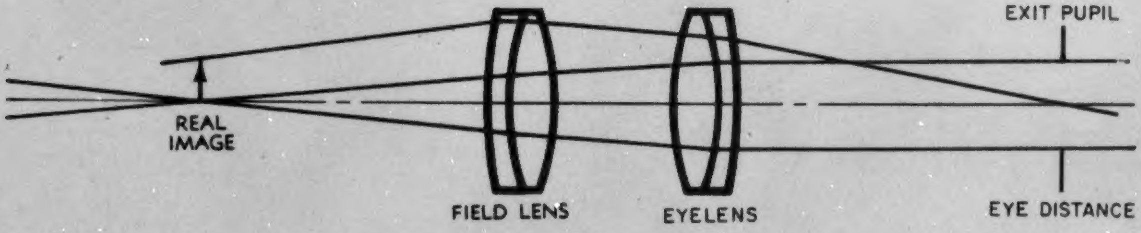
Symmetrical and Two Doublet

Symmetrical and two-doublet eyepieces are constructed of two cemented, achromatic doublets (fairly close together) with their positive elements facing each other (figure 5-19). If the doublets are identical in every respect (diameters, focal lengths, thickness, and index of refraction), the eyepiece is symmetrical. If the doublets differ in one respect or another, however, they are considered a two-doublet eyepiece. The eyelens of the two-doublet



137.140

Figure 5-18.—Kellner eyepiece.



137.142

Figure 5-19.—Symmetrical eyepiece.

eyepiece is generally slightly smaller in diameter and has a shorter focal length than the field lens.

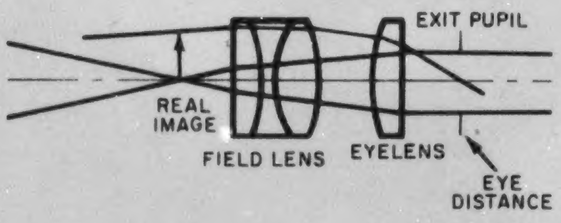
Symmetrical and two-doublet eyepieces are often used in fire control instruments which recoil. The eye distance on these instruments must be fairly long to prevent the eyepiece from striking the gunner's eye. These eyepieces provide the necessary eye relief as well as a large exit pupil at moderate magnification. For this reason, symmetrical eyepieces—along with Kellner—are used extensively in optical instruments, particularly rifle scopes and binoculars.

Orthoscopic

The orthoscopic eyepiece is illustrated in figure 5-20. It employs a planoconvex triplet field lens and a single planoconvex eyelens with the curved surfaces of both elements facing each other. It is free from distortion and is useful in high-power telescopes because it gives a wide field and high magnification with sufficient eye relief. It is also a very useful eyepiece for rangefinders because it permits the use of any part of the field. It was named orthoscopic because of its freedom from distortion.

Internal Focusing

Very often it is mandatory that an instrument be completely sealed to keep out moisture and dirt. To do this and still be able to accommodate for the visual variations between different observers, there are several types of internal focusing eyepieces that can be used. These usually consist of three elements. One type is illustrated in figure 5-21. The eyepiece has a field lens, intermediate lens, and eyelens, all of which are cemented doublets.

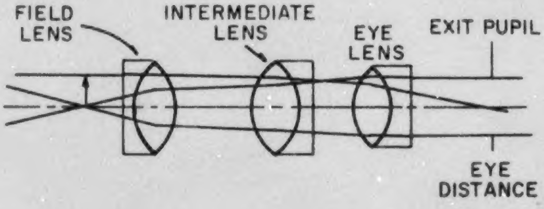


137.143

Figure 5-20.—Orthoscopic eyepiece.

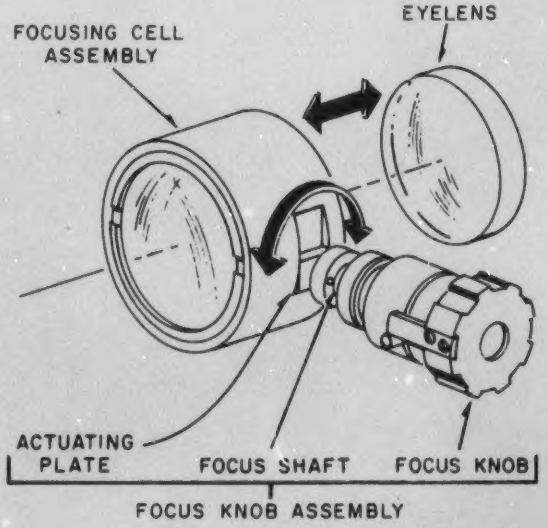
The field lens and intermediate lens are mounted in a cell which can be moved longitudinally by rotation of the focusing knob. The eyelens is fixed and acts as a seal for the eyepiece. Figure 5-22 is a mechanical drawing of the focusing operation.

Internal focusing eyepieces are not limited to the three-doublet combination as shown in figure 5-21. For example, the Mk 102 Mod 3 telescope has a triplet field lens, doublet



137.513

Figure 5-21.—Internal focusing eyepiece.



137.514

Figure 5-22.—Mechanical schematic of internal focusing eyepiece.

intermediate, and singlet eyelens. The basic principle is the same in all combinations; the field lens converges light rays which otherwise would miss the intermediate lens, and the intermediate lens converges light which would otherwise miss the eyelens. The eyelens converges light to the exit pupil.

SIMPLE TELESCOPES

A telescope is an optical instrument containing a system of lenses or mirrors, usually, but not always, having magnification greater than unity, which renders distant objects more clearly visible by enlarging their images on the retina of the eye. In its simplest form, a telescope consists of two parts: a lens, or mirror, called the objective, and an eyelens, or eyepiece.

The function of the objective is to gather as much light as possible from the object and converge it to form a real image of that object. In some telescopes, the objective does not form a real image; this will be explained later in the chapter.

ASTRONOMICAL

The ancient astronomers had only the naked eye to observe and record the relative positions of the moon, sun, stars, and planets. The invention of the telescope about 1600 A.D. was a major breakthrough which has led to the highly technical instruments that are used today.

In the process of refraction and reflection by a telescope system, the image becomes inverted. With astronomical bodies, it makes little difference whether or not the object is viewed upside down. Telescopes that give the observer an inverted view are called astronomical telescopes. Since they need no erecting system, they are optically more simple. For this reason we study them first in our attempt to understand the general nature of the telescope.

Reflecting

In chapter 4 you studied the effect that concave mirrors have on light. In most astronomical telescopes, especially the big ones, the objective is a concave mirror instead of a lens. There are several reasons for this. When you are looking at distant stars, you want the image to be as bright as possible. The brightness of an image depends on the diameter of the mirror that forms it. There is no light lost due to passage through optical elements.

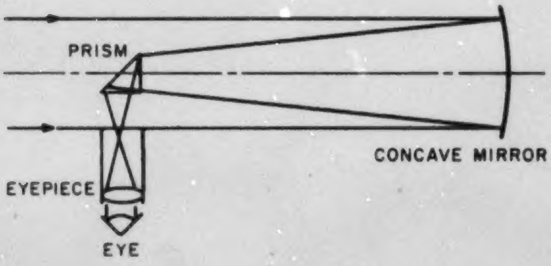
There is a practical limit to the diameter of a lens. The biggest refracting telescope we know about is at the Yerkes Observatory; the diameter of its objective is 40 inches. A lens much bigger than that could not be mounted in a telescope barrel. In the first place, it would not be easy to cast a big enough piece of good optical glass. In the second place, a lens bigger than 40 inches would sag under its own weight. (Remember, glass is a liquid.) The lens would have to be extremely heavy, and it could be supported only at its edges. It may easily sag 20 or 30 millionths of an inch, which is all the sag you need to ruin the image.

Another thing: an objective lens must have at least two elements to correct aberrations, which means you must grind and polish at least four surfaces. With a mirror, you have only one surface to grind and polish. And of course, a mirror has no chromatic aberration. Since the light does not pass through the mirror, the glass does not need to be optically perfect all the way through.

At one time, the biggest reflecting telescope in the world was in the observatory on Mt. Palomar, in southern California. Its objective is a concave mirror 200 inches–about 17 feet in diameter. The Corning Glass Company at Corning, New York made the blank for it from Pyrex glass. (Pyrex expands and contracts less than ordinary glass when the temperature changes.) To keep it from developing strains, the mirror was annealed in an electric furnace. Its temperature was reduced just 1° each day. Interestingly enough, the Cohocoton River runs right beside the glass works, and in 1936 the river flooded. The water did not reach the mirror, but it took out the power line and cooled the annealing furnace. They had to start all over with a new mirror.

The California Institute of Technology had spent 4 years grinding the mirror when they were interrupted by World War II. After the war they finished the grinding and polishing and plated the reflecting surface with a thin film of aluminum. They also completed the telescope mount. The mount supports the weight of the objective and the platform the observer stands on. It automatically—and very accurately—tracks the stars as they move across the sky.

Figures 5-23 and 5-24 illustrate two types of reflecting telescopes. Notice that a reflecting element is placed in the path of incident light in both examples. Since the concave mirrors are rather large, and since incident light comes from such a great distance, the placement of a small prism or mirror in the path of light will have no adverse effect on the final image. Also notice that the images formed are located outside the body of the telescopes, allowing direct observation of celestial targets or substitution of a photographic plate for the eyepiece.

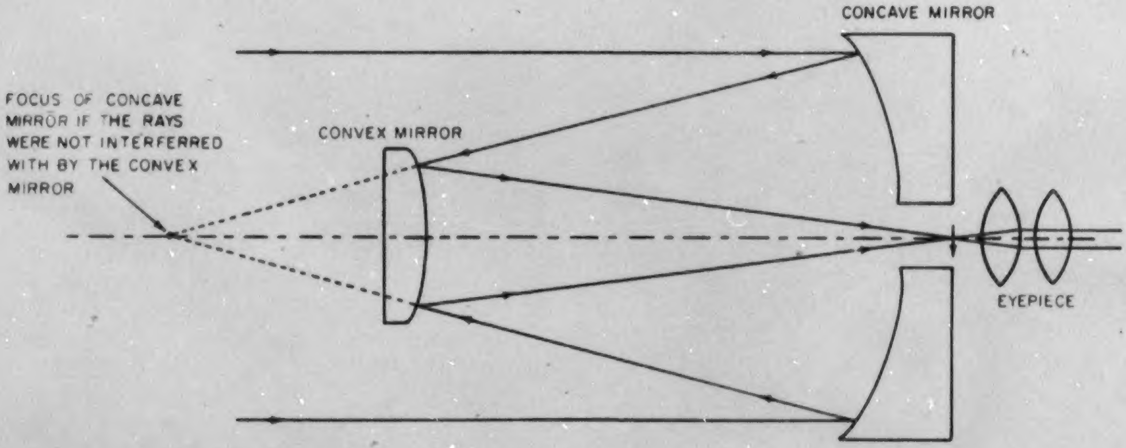


137.147

Figure 5-23.—Newtonian reflecting telescope.

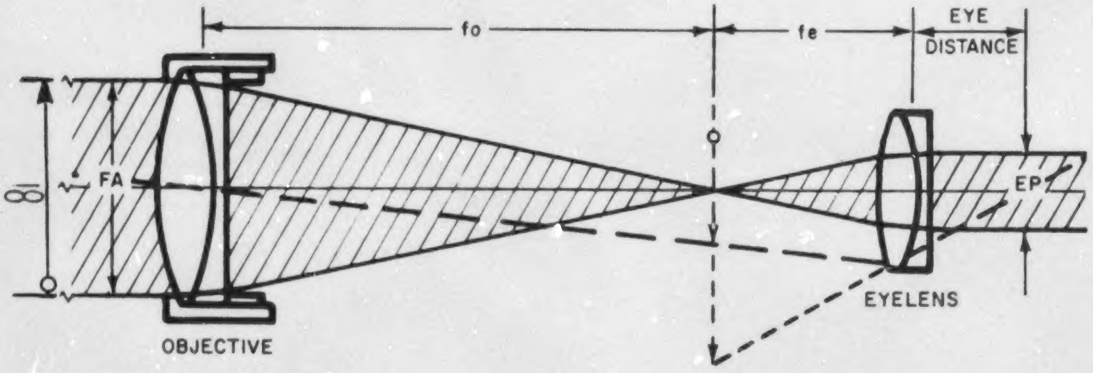
Refracting

Figure 5-25 shows a simple astronomical telescope. We will use this illustration to explain various optical principles common to more complicated arrangements presented later. Note that the parallel light rays entering the objective lens are refracted and converge to a focal plane. (The image plane and the focal plane coincide when parallel rays are refracted by any lens.) In the focal plane of the objective lens a real, inverted, reverted, diminished image of the object is formed. The eyepiece is so placed that the image formed by the objective lens is located at the primary focal point of the eyepiece. The diverging rays, diverging from the real image, enter the eyepiece, are refracted, and emerge parallel to the optical axis of the telescope. The eyepiece acts as a magnifying lens to magnify the real image. If you look through the telescope eyepiece, you see a virtual, inverted, reverted, enlarged image which is formed at infinity.


CONCAVE MIRROR
FOCUS OF CONCAVE MIRROR IF THE RAYS WERE NOT INTERFERRED WITH BY THE CONVEX MIRROR
CONVEX MIRROR
EYEPIECE

137.148

Figure 5-24.—Cassegranian reflecting telescope.



137.159

Figure 5-25.–Simple astronomical telescope.

In an astronomical telescope in which the focal points of the objective lens and the eyepiece lens coincide, the length of the telescope is the sum of the focal lengths of the two lenses.

Before you can fully understand the telescope, you must have a thorough knowledge of several other optical terms.

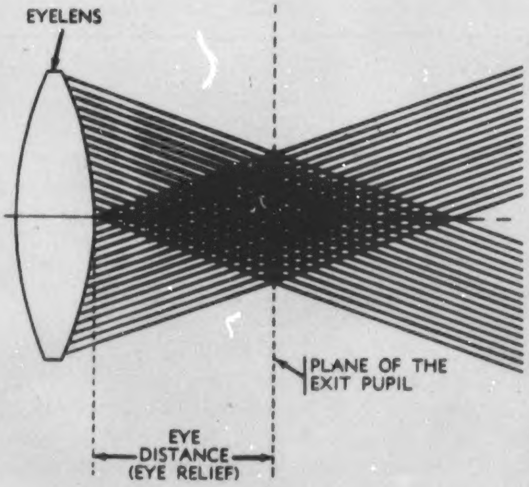
FREE APERTURE: A term that denotes the entrance pupil of the objective which is limited by the inside diameter of the objective mount or the inside diameter of the objective lens retainer ring (FA in figure 5-25). The entrance pupil can be viewed as such from the objective end of the instrument, and it can be measured with a ruler directly across the objective.

EXIT PUPIL: The term given the diameter of the bundle of light leaving an optical system. You can see this small circle, or disk of light, by looking at the eyepiece of an instrument that is directed at an illuminated area. The exit pupil is actually a real image of the objective lens aperture. The diameter of the exit pupil is equal to the diameter of the entrance pupil divided by the magnification of the instrument. The exit pupil is designated EP in figure 5-25.

EYE DISTANCE: Often called eye relief, the term given to the numerical measure of the distance from the rear surface of the rear eyelens to the fixed position of the exit pupil (fig. 5-26).

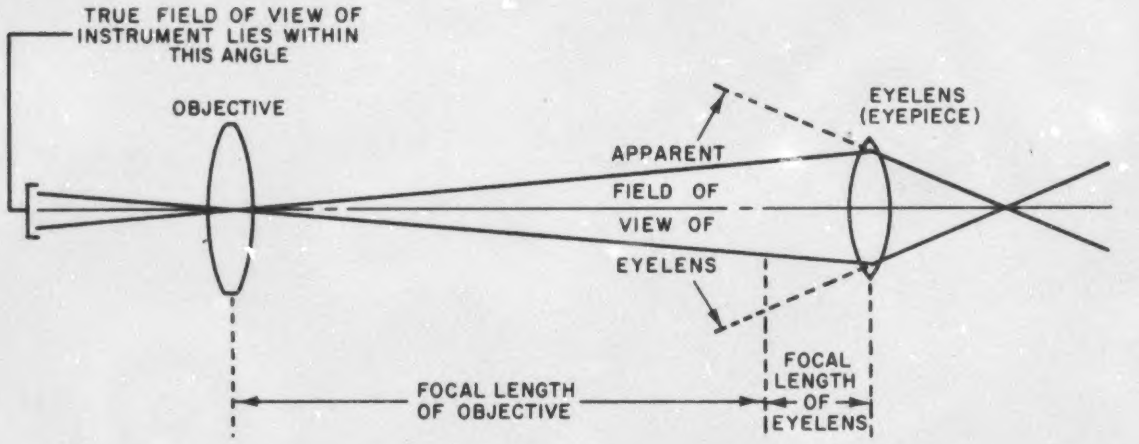
TRUE FIELD: The width of the target area, or field, that can be viewed. More specifically, it is the maximum cone or fan of rays, subtended at the entrance pupil, that is transmitted by the instrument to form a usable image (fig. 5-27).

APPARENT FIELD: The size of the field of view angle as it appears to the eye. It is approximately equal to the magnification of the



137.515

Figure 5-26.–Eye distance and exit pupil plane.


TRUE FIELD OF VIEW OF INSTRUMENT LIES WITHIN THIS ANGLE
OBJECTIVE
EYELENS (EYEPIECE)
APPARENT FIELD OF VIEW OF EYELENS
FOCAL LENGTH OF OBJECTIVE
FOCAL LENGTH OF EYELENS

137.514

Figure 5-27.—True field and apparent field.

instrument times the angle of the true field (fig. 5-27).

TERRESTRIAL TELESCOPES

A terrestrial telescope gets its name from the Latin word *terra*, which means earth. A terrestrial telescope is used to view objects as they actually appear on earth, normal and erect.

Galilean Telescope

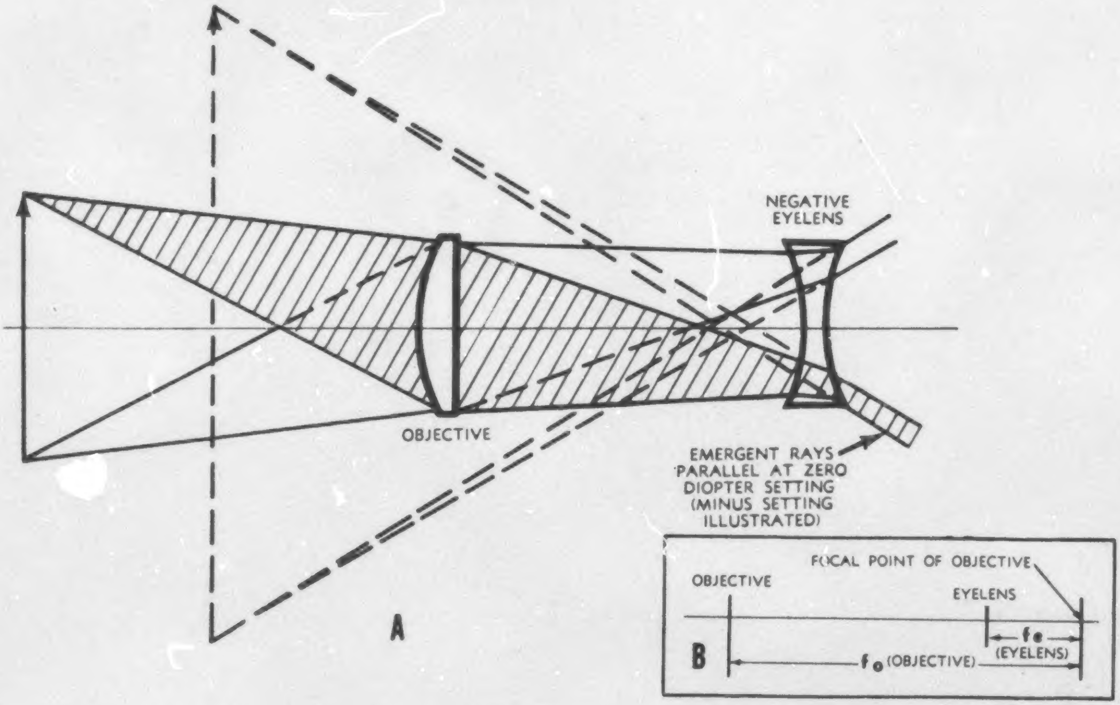
The simplest form of terrestrial telescope was invented by the scientist Galileo. His first telescope had a power of 30 (fig. 5-28A). Its eyepiece consists of a negative eyelens positioned a distance equal to its focal length (f_e, fig. 5-28B) in front of the objective focal point. Such positioning of the negative eyelens makes converging rays from the objective diverge before they form a real image; therefore, no real image exists in this optical system. If you look through the eyelens you see an enlarged, erect, virtual image of the object, which appears to be at a point between 10 inches and infinity.

The relation of the optical elements in a Galilean telescope (fig. 5-28B) is referred to as the ZERO DIOPTER SETTING, which means that all light rays from any point source located at infinity emerge from the eyepiece parallel. If the eyelens is moved in and out, however, the emergent light rays converge or diverge and the instrument can therefore be adjusted for either farsighted or nearsighted eyes and also for objects at various distances.

In a Galilean telescope, the diameter of the objective controls the field of view because the objective is both the field stop and the free aperture. No exit pupil is formed because there is no real image plane in this system. Magnification in a Galilean telescope is accomplished by increasing the visual angle, as shown by the dash line in figure 5-28A.

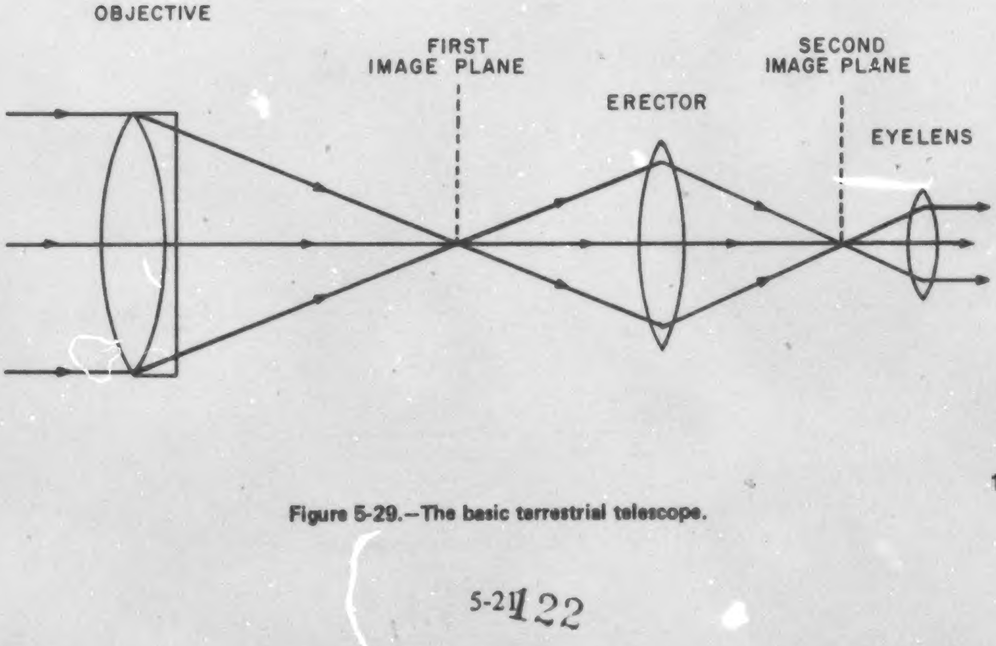
Lens Erecting Systems

Any astronomical telescope can be converted to a terrestrial telescope by inserting a lens between the eyepiece and the objective to erect the image. Figure 5-29 shows the optical elements of the basic form of terrestrial



137.150

Figure 5-28.–Galilean telescope.



137.516

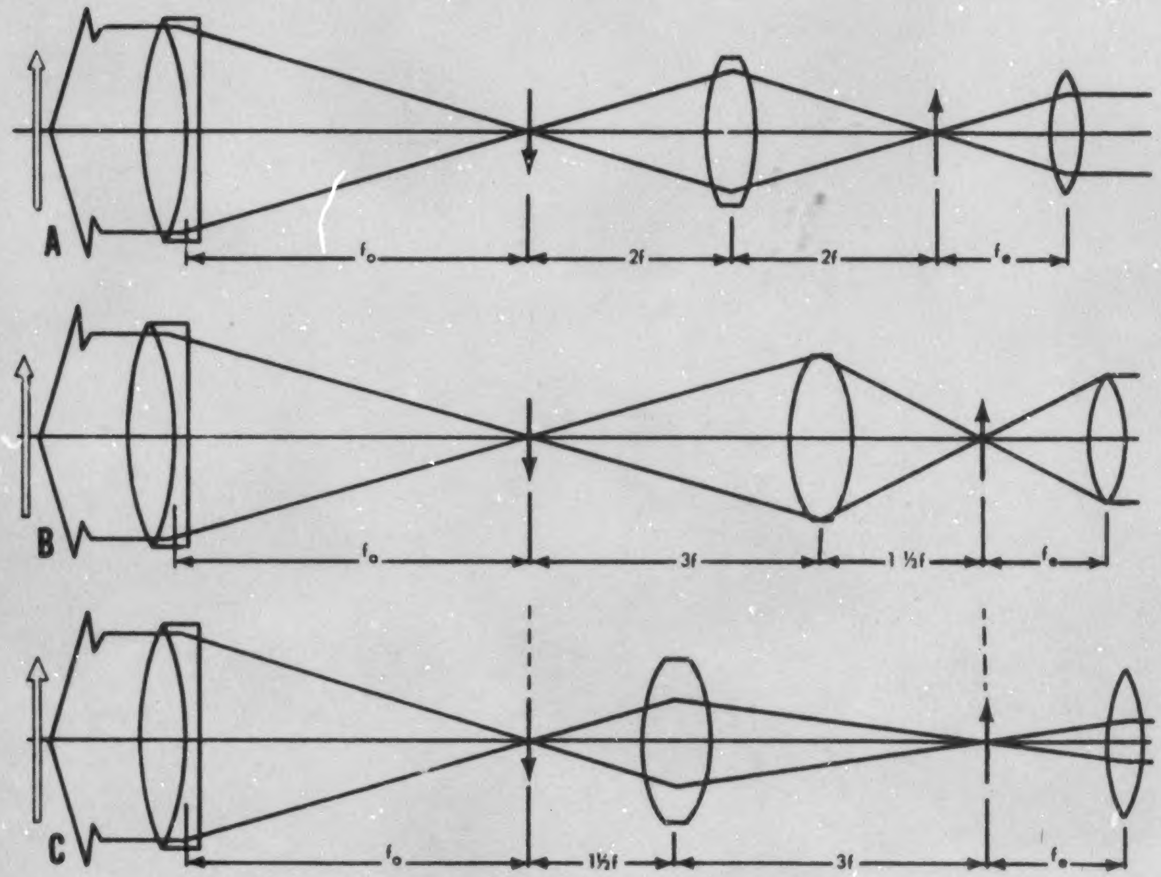
Figure 5-29.–The basic terrestrial telescope.

telescopes. Note the position of the REAL IMAGES.

In addition to erecting the image, proper positioning of the erector system can also have a direct effect on the magnification of the instrument. The possible arrangement of optical elements in a single erector telescope is illustrated in figure 5-30. Note that the parallel rays entering the objective lens from an infinity target are refracted to form a real inverted image in the focal plane of the objective lens. Rays which leave the real image diverge as though the image itself were an object. When you place an erector lens behind the objective image, the erector receives the diverging rays and refracts them to form an image behind the erector. The image formed by the erector is then magnified by the eyelens.

In figure 5-30A, the erector is 2 focal lengths from the objective image plane, and the image the erector forms is 2 focal lengths from the erector. As you recall from chapter 4, the two images will be the same size. Consequently, the magnification of this telescope will depend on the focal length of the objective (f_o) divided by the focal length of the eyelens (f_e).

$$M = \frac{f_o}{f_e}$$



137.152

Figure 5-30.—One erector telescope.

Now refer to figure 5-30B. Notice that the erector is located 3 focal lengths from the objective image plane and that it forms an image 1 1/2 focal lengths behind the lens. In this case, the erector will change the size of the image presented to the eyelens.

Remember the formula magnification explained in chapter 4:

$$M = \frac{D_i}{D_o}$$

If D_o is 3 focal lengths and D_i is 1 1/2 focal lengths, then:

$$M = \frac{1.5}{3} = .5$$

the image formed by the erector is only half the size of the objective image.

What will this do to the magnification of the telescope? Assume the objective focal length (f_o) is 4 inches, and the eyelens focal length (f_e) is 1 inch:

$$M = \frac{f_o}{f_e} = \frac{4}{1} = 4 \text{ power}$$

Now, multiply the basic telescope magnification (4) by the magnification of the erector (.5):

$$4 \times .5 = 2 \text{ power}$$

Figure 5-30C shows the position of the erector lens reversed in relation to figure 5-30B. How will this affect the magnification of the telescope? (Use the same figures as in the previous example).

Erector magnification equals:

$$M = \frac{D_i}{D_o} = \frac{3}{1.5} = 2$$

Basic telescope magnification equals:

$$M = \frac{f_o}{f_e} = \frac{4}{1} = 4$$

Total magnification equals:

$$4 \times 2 = 8$$

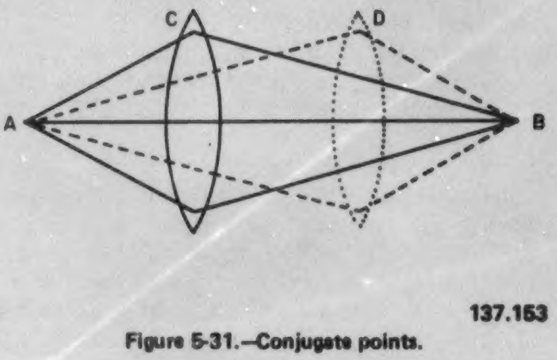
Figure 5-30A illustrates a basic terrestrial telescope with a magnification of 4 (sometimes shown as 4X). Depending on the position of the erector lens, magnification can be changed to 2X (figure 5-30B) or 8X (figure 5-30C). What we have demonstrated is a change of power, or change of magnification system.

Change of power in an optical system depends on the law of reversibility. Figure 5-31 shows the conjugate points (A and B) which correspond with lens positions (C and D). One is just the reverse of the other.

The image planes (A or B) do not change when the lens is in position C or D (fig. 5-31). For any other position of the lens, the observer could not focus on the final image with the eyepiece. Therefore, the erector must be at one or the other position to take advantage of the conjugate points.

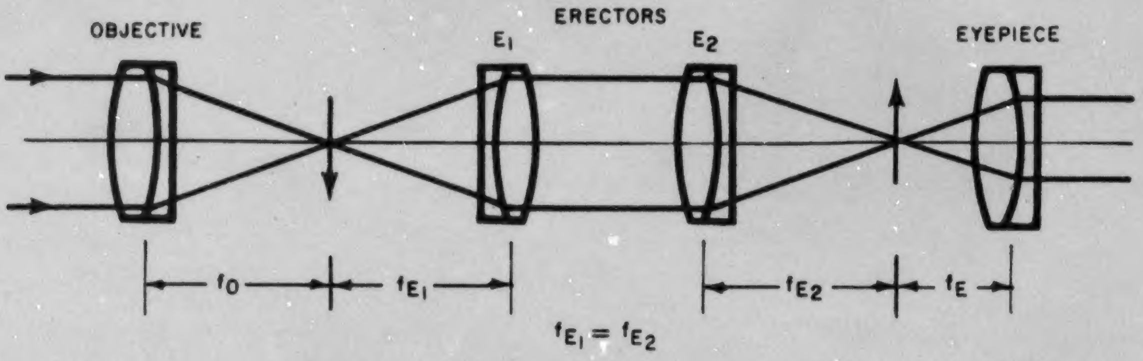
Two-Erector

Refer to figure 5-32 to see how a terrestrial telescope with two erecting lenses is constructed. The erectors shown are SYMMETRICAL: that is, they are identical in every respect–diameter, thickness, index of refraction, and focal lengths. ASYMMETRICAL erectors (with different focal lengths) may also be used in this type of telescope for design purposes or to help increase magnification, which the objective and eyepiece alone could not do.



137.153

Figure 5-31.—Conjugate points.



137.155

Figure 5-32.—Two erector telescope.

The erecting lens is positioned 1 focal length from the objective focal plane. The divergent rays which enter the erecting lens are refracted and emerge parallel to the optical axis.

Since the rays that emerge from the first erecting lens are parallel, the second erecting lens may be placed at any reasonable distance from the first erector, because the rays which enter the second erecting lens are always parallel, regardless of the amount of lens separation. Separation of the erectors in fixed-power telescopes is generally the sum of their focal lengths.

Parallel rays which enter the second erecting lens are refracted and converge to the focal plane to form a real, erect image.

The eyepiece of the telescope is again positioned as necessary to have the image of the second erector at its focal plane. If you look through the eyepiece of the telescope, you see a virtual, erect, enlarged image.

A two-erector telescope can also be constructed as a change of power instrument by moving the erectors together as a unit in the same direction (with their separation fixed). Their distance from the real image formed by the objective lens must be 1 1/2 EFL, or 3 EFL of the erecting lens combination. The two erecting lenses function together as a single thick lens to produce an image in the same manner as the single erector lens used for the same purpose.

Most optical systems are designed to magnify a target. An important fact to remember about magnification is that when power (magnification) is increased, the field of view decreases; you can see details of the target better when magnified, but you cannot see as much of the target.

When using a hand held optical instrument, any movement you make will be increased in direct proportion to the power of the instrument. For this reason, hand held instruments are usually limited to about 6X. The Navy does use several types of telescopes at 10X and 16X, but they are very difficult to hold on target.

Variable Power

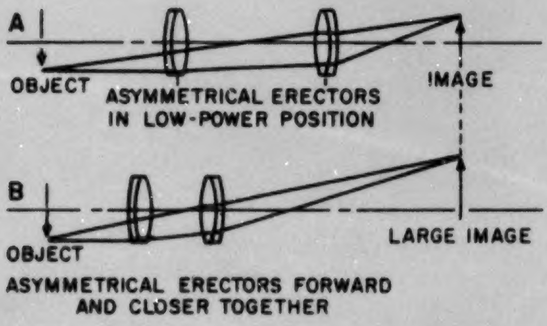
With a variable power telescope you can change the magnification continuously between two limits. If you look through a variable power instrument and gradually increase its magnification, you will get the same effect that a television or movie cameraman gets when he zooms in on an object. It appears as if the camera is moving toward the subject while the action is going on. Even simple home movie cameras have this feature.

In the change of power telescope (fig. 5-30), there are only two positions of the erecting lens for which the two image planes are conjugate; that is you cannot vary the power continuously because the image will be out of focus when the erecting lens is in an intermediate position. The only way to keep the two image planes conjugate throughout the travel of the erector lens is to change its focal length continuously while you move it.

It is impossible to change the focal of a lens, but, if two lenses are used in combination (figure 5-33), you can vary the EFL of the combination and still maintain the same focal plane.

In figure 5-33, the object is the objective image plane. At the low power position (fig. 5-33A), there is little difference between the size of the two images. In figure 5-33B, both lenses are moved different distances toward the objective, and a significant enlargement of the image is produced by the erector combination. Notice that the image plane remains stationary.

At any position between the low and high power positions of the erectors, the image will be in sharp focus if the mechanism that moves the erectors is properly designed. A variable power system will usually provide three to four times as much magnification in the high power position than in the low power (3X to 9X or 6X to 24X rifle scopes).


A
OBJECT
ASYMMETRICAL ERECTORS IN LOW-POWER POSITION
IMAGE
B
OBJECT
LARGE IMAGE
ASYMMETRICAL ERECTORS FORWARD AND CLOSER TOGETHER

137.156

Figure 5-33.—Variable magnification in two erector telescope.

Prism Erecting Systems

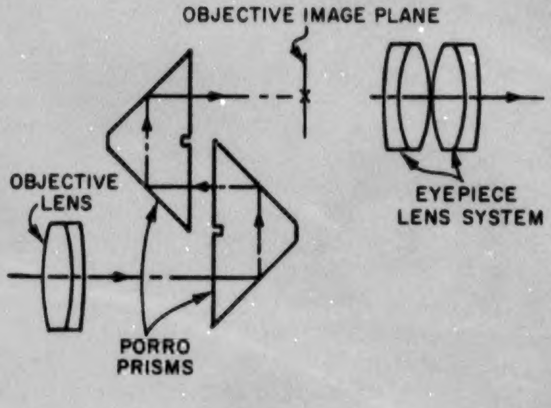
Thus far, we have discussed telescopes with one or two erecting lenses and a straight line of sight to the target. The Navy uses many types of instruments which must present an erect image, but prisms are used as erectors.

Figure 5-34 illustrates a telescope with two porro prisms placed within the focal length of the objective lens. As you recall from Chapter 3, two porro prisms invert and revert the line of sight. Thus, they cancel the inverted, reverted objective image and the observer views an erect, normal image.

A porro prism cluster used in this manner will provide a very compact instrument. Trace the path of light through the prisms, then imagine how much longer the instrument would be if an erector lens were used.

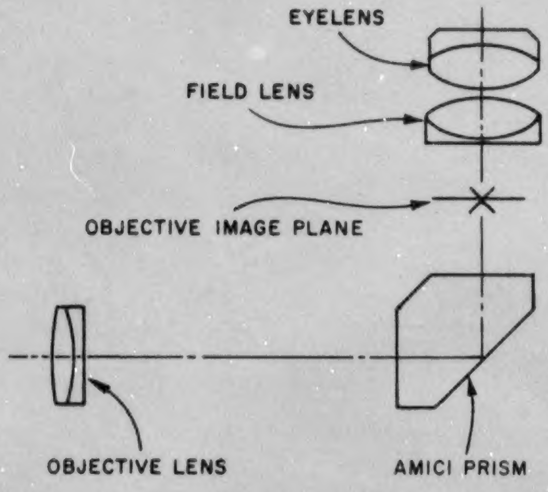
The line of sight through an instrument using a prism cluster will be offset but still will be considered a straight line telescope.

In figure 5-35, a 90° roof edge or Amici prism is used as an erector. Some similar instruments use a 60° roof edge prism. In either case, the line of sight is deviated but the observer views an erect, normal image.



137.556

Figure 5-34.—Porro prism erecting system.



137.557
Figure 5-35.—Amici prism erecting system.

Various other combinations of prisms, mirrors, and lenses are used in military optical instruments, most of which you will see later. The optical system used in any particular instrument depends on how the instrument will be used and where it will be mounted.

GUNSIGHT TELESCOPES

The Navy uses a wide variety of terrestrial telescopes as gunsights, some of which are very complex in their construction. This section will give you a basic understanding of the function and design principles of the telescope used as a fire control instrument. Some of the simple gunsight telescopes are covered in more detail in another chapter of this book. Anytime an Opticalman engages in repair or overhaul of a particular gunsight, or any optical instrument, he must **ALWAYS** use the technical manual that applies to that instrument.

The gunsight telescope is used to improve the view of distant targets as follows:

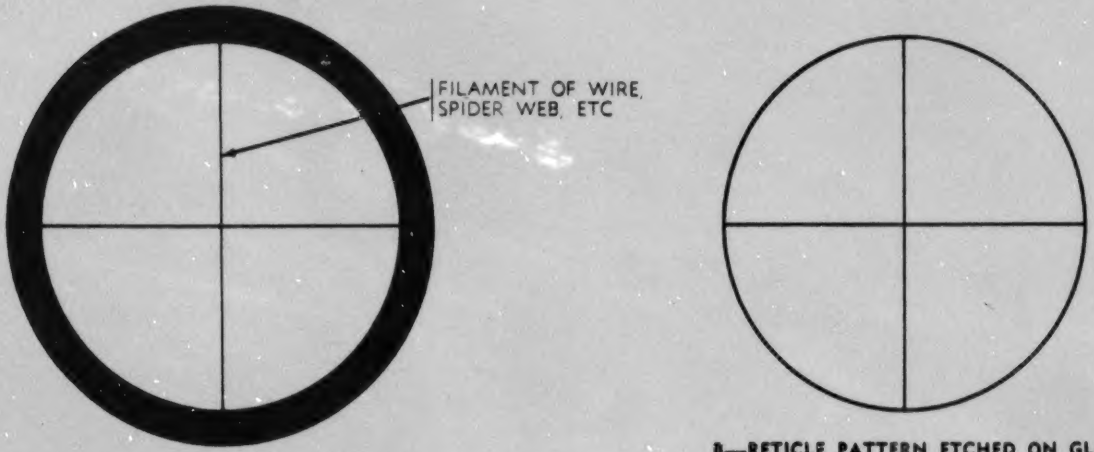
1. It gathers and concentrates a greater quantity of light from the target than the unaided eye can gather, thus rendering the target more distinct.
2. It erects the target image and superimposes a reticle upon it, thus sharply defining the line of sight to the target.
3. It magnifies the target image so that the distant target appears closer.

In many instances, the eyepiece of gunsight telescopes is inclined at an angle with respect to the line of sight, so that the observer can comfortably view targets at various angles.

Reticles, such as those shown in figure 5-36, are used in fire control instruments to superimpose markings or a predetermined pattern of range and deflection graduations on a target. When the reticle is placed in the center of the field of view, it represents the axis of the gunsight and then can be aligned with the axis of the bore of the weapon for short range firing, or it can be fixed at a definite angle to the bore for long range firing. A reticle is used as a reference for sighting or aiming, or it can be designed to measure angular distance between two points. Since the reticle is placed in the same focal plane as a real image, it appears superimposed on the target. In a gunsight that has a lens erecting system, the reticle can be placed either in the objective image plane or in the erector focal plane. If the erecting system increases magnification, when the reticle is placed in the image plane of the objective, the reticle lines will appear wider than if they were placed at the focal point of the eyepiece. Therefore, the reticle usually is placed behind the erecting system.

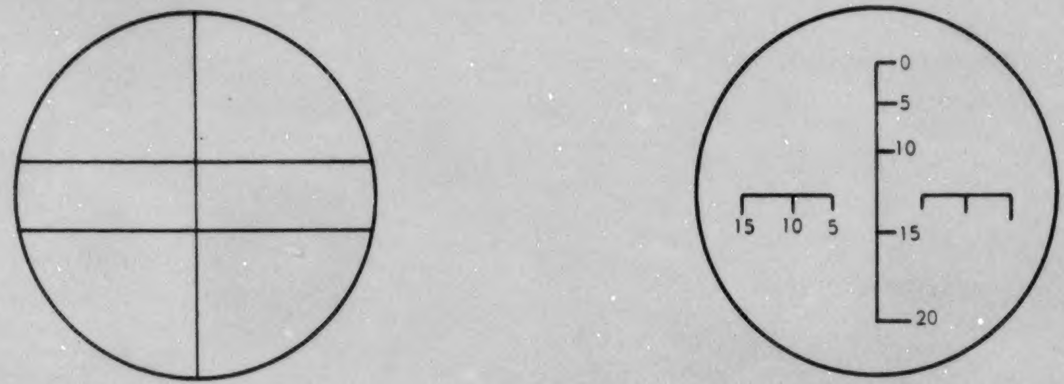
Parallax

Parallax in an optical instrument is a defect of primary importance. In a correctly adjusted instrument, the image of the viewed object is formed in the same plane as that in which the reticle lies. If this does not occur (fig. 5-37), parallax is present. You can detect parallax by moving your eye back and forth across the eyepiece of the instrument. The appearance of relative motion between the reticle and the field of view indicates the presence of parallax (fig. 5-38).



A—SIMPLE CROSSHAIR IN RETICLE HOLDER

B—RETICLE PATTERN ETCHED ON GLASS



C—STADIA LINES FOR ANGULAR MEASUREMENT

D—ETCHED DESIGN WITH NUMERALS

137.139

Figure 5-36.—Examples of reticle patterns.

To correct for parallax, shift the optical elements of the telescope until the reticle lies in the precise plane of the real image. The technical manual for each type of instrument gives detailed procedures for making this adjustment.

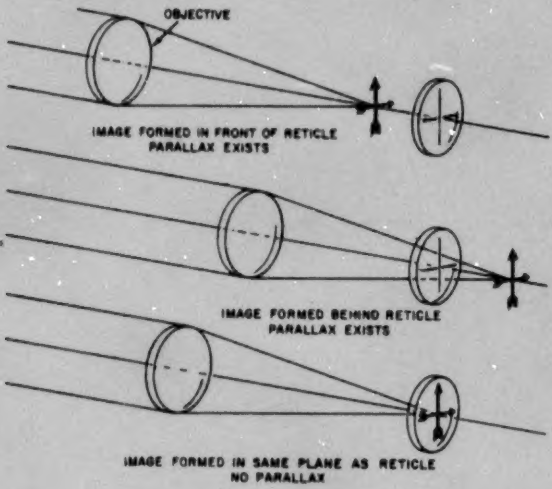
TELESCOPE MAGNIFICATION

In our explanation of various types of telescopes, we have discussed magnification and the various methods of determining the power of an optical system. It is appropriate that we now review and amplify these procedures.

To determine the power of a telescope WITHOUT A LENS ERECTING SYSTEM, there are three methods which can be used:

1. Divide the focal length of the objective by the focal length of the eyepiece (EFL):

$$M = \frac{f_o}{f_e}$$


OBJECTIVE
IMAGE FORMED IN FRONT OF RETICLE
PARALLAX EXISTS
IMAGE FORMED BEHIND RETICLE
PARALLAX EXISTS
IMAGE FORMED IN SAME PLANE AS RETICLE
NO PARALLAX

137.517

Figure 5-37.—Optical parallax.

2. Divide the apparent field by the true field:

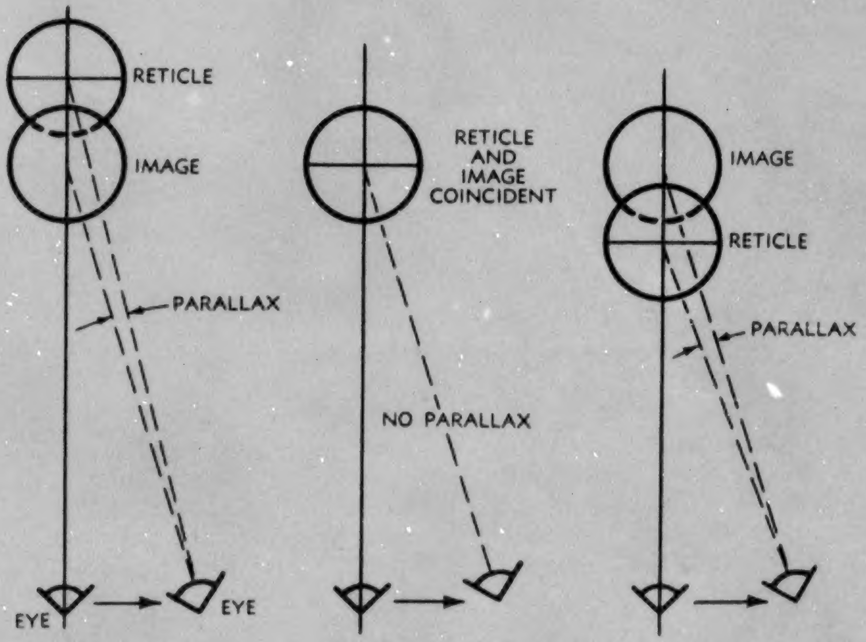
$$M = \frac{\text{App field}}{\text{True field}}$$

3. Divide the objective lens opening (free aperture) by the size of the exit pupil:

$$M = \frac{FA}{EP}$$

To determine the power of a telescope with a lens erecting system, you must multiply the formula (f_o/f_e) by the magnification produced by the erector lens system (D_i/D_o).

$$M = \frac{f_o}{f_e} \times \frac{D_i}{D_o}$$



137.158

Figure 5-38.—Relative motion of parallax.

The other two formulas, App Field/True Field and FA/EP will work for any optical system.

Most optical instruments have an attached nameplate which indicates the power (3X, 6X, 10X, etc.). Technical manuals on optical equipment have all specifications for the instruments listed (power, apparent field, true field, length, weight, type of instrument).

At times you may be called on to work with an unfamiliar instrument, or you might need to determine certain characteristics of a portion of the optical system. In such cases, you will find the information contained in this manual most useful.

You will recall that entrance pupil means the clear aperture of the objective, and that the exit pupil is the diameter of the bundle of light which leaves an optical system. The exit pupil is actually an image of the objective lens produced by the eyelens.

You can measure the diameter of the entrance pupil with a transparent metric scale–directly across the objective. This method of measurement is sufficiently accurate for most purposes.

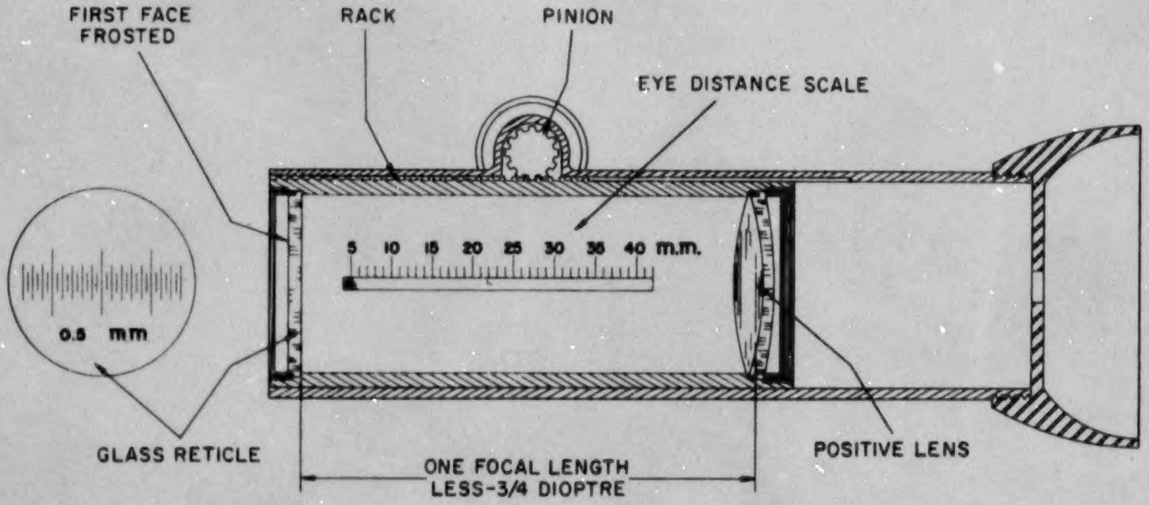
You can determine the diameter of the exit pupil of a telescope in three simple steps:

1. Point the instrument toward a light source (out a window, for example).
2. Insert a piece of plain paper in the plane of the exit pupil.
3. Measure the diameter of the exit pupil on the paper.

The best way to measure the diameter of an exit pupil, however, is with a dynameter. See figure 5-39. A dynameter is a magnifier or an eyelens with a fixed reticle on a frosted glass plate, both of which move as a unit within the dynameter tube.

To measure the exit pupil with a dynameter, place the dynameter on the eyepiece of the instrument you are testing, and focus the dynameter until the bright disk of the exit pupil is sharply defined on its frosted reticle. Then compare the diameter of the exit pupil with the dynameter reticle (usually graduated in .5 mm) and read the eye distance on the scale on the dynameter tube.

To keep the image of the exit pupil in focus, the frosted reticle must be moved a distance



137.160

Figure 5-39.–Dynameter.

equal to the eye distance of the instrument being tested.

You have already learned that the true field of an optical instrument is the angular area of a target which can be transmitted through the objective of an instrument to form an image. The apparent field is the amount this small angle is magnified by the eyepiece system.

You can approximate the actual amount of apparent and true field of an instrument by using the following procedure:

Point the instrument you are testing toward a prominent target and adjust it to a sharp focus. Observe some distinctive feature of the target at the extreme left and right sides of the field. Now lay a plastic protractor on a table or windowsill and put a small straight pin through the center. Using the pin as a sight, place a card on the curved edge of the protractor and align the pin, card edge, and one edge of your selected target. Next, without moving your head or the protractor, align another card with the opposite side of your selected target. You can read the approximate true field, in degrees, from the protractor. If you are very careful, you may be accurate to within 1/2 degree.

To determine the apparent field, turn the instrument around, look at a target through the objective lens, and align the extreme edges of the field with some easily distinguished landmarks. Now, repeat the procedure with the protractor to determine the size of the apparent field angle.

Remember, if you are using a telescope of 6X to look at a target through the objective end, the target will only be 1/6 as large as it appears to your unaided eye. Therefore, you must select very prominent features at the edges of the field if you attempt to measure apparent field in this manner.

THE MICROSCOPE

An instrument that is used to produce an enlarged image of very small nearby objects is called a microscope. Microscopes are of two types, simple and compound. A simple microscope produces but one image of an object and consists of a convergent lens located at the first focal plane of the eye. In effect, this is just a simple magnifying lens as covered in chapter 4. In a compound microscope, the objective lens forms a primary image which is further magnified by the eyepiece.

You perhaps used a compound microscope to look at minute plants and animals when you were in high school. Such an optical instrument so magnifies small objects that it increases the usefulness of the eyes at short distances. The eyes, by nature, are long-range optical instruments of high acuity.

Refer now to figure 5-40, which shows one of the simplest types of compound microscopes. Study all details and the nomenclature. Note the position of the eye, the eyepiece, the objective, and the object. Then observe the positions of the real and virtual images. This illustration should clarify much of the information you have studied concerning image formation, magnification, and the relationships between focal length and image and object distance.

To find the magnification of a compound microscope, you must do two things: First, determine the magnification of the objective; then multiply by the magnifying power of the eyepiece.

Suppose the objective has the following characteristics:

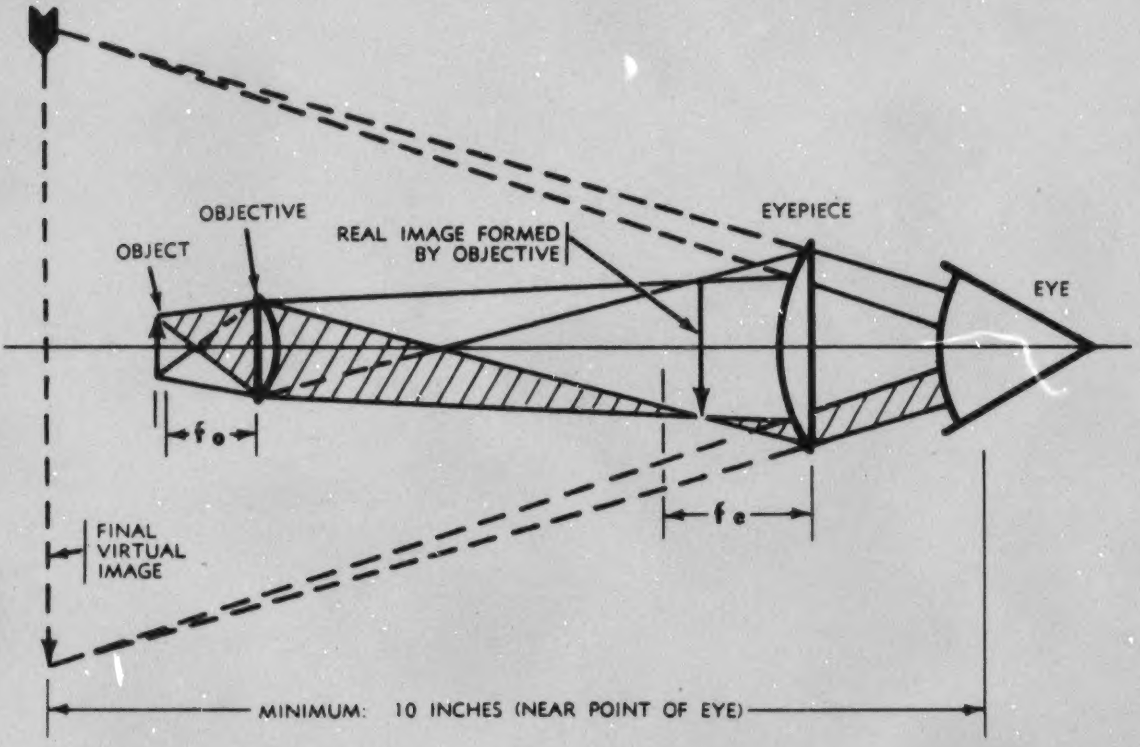
$$D_o = .5 \quad D_i = 6 \text{ inches}$$

then:

$$\text{Mag} = \frac{D_i}{D_o} = \frac{6}{.5} = 12$$

If the eyepiece has a focal length of .5, then:

$$\text{MP} = \frac{10}{\text{fl in.}} = \frac{10}{.5} = 20$$


OBJECTIVE
OBJECT
REAL IMAGE FORMED BY OBJECTIVE
EYEPIECE
EYE
f_o
f_e
FINAL VIRTUAL IMAGE
MINIMUM: 10 INCHES (NEAR POINT OF EYE)

137.134

Figure 5-40.—Image creation by a compound microscope.

The magnification of the microscope is therefore:

12 X 20= 240 power

Magnification in a microscope depends upon the focal lengths of the objective and the eyepiece and the distance between these two optical elements. A compound microscope can magnify an object about 2,000 times (diameters), but little, if any, increase in the details of an object is obtained after the object has been magnified 400 times.

CHAPTER 6

DESIGN AND CONSTRUCTION

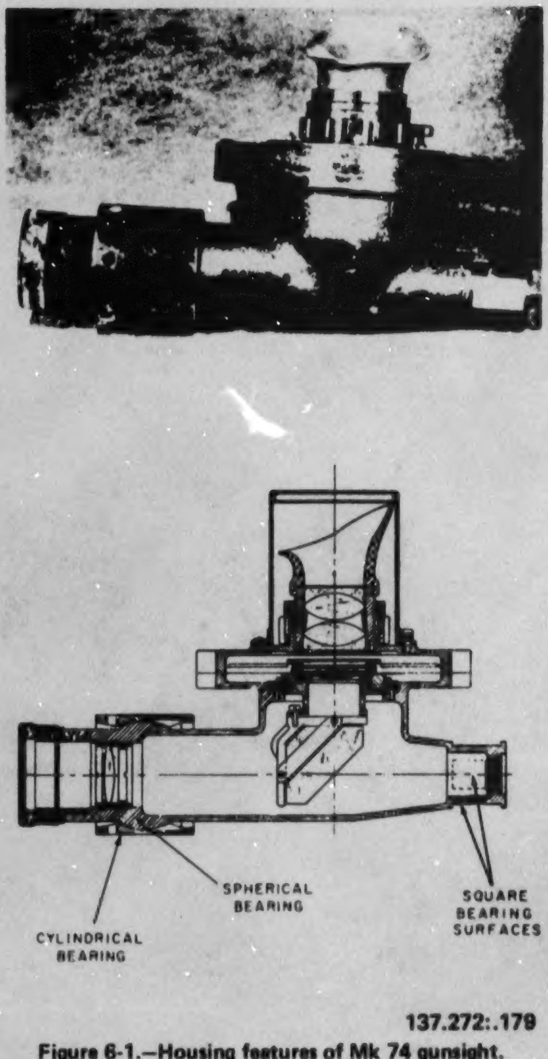
MECHANICAL FEATURES

Optical instruments used in the Navy are complicated, delicate, precision instruments. A small error in alignment, a foreign particle, or a trace of moisture can render such an instrument ineffective or useless. These delicate instruments get almost constant use and are subjected to all kinds of weather conditions and rough treatment. To keep them in working condition, the Navy depends on your skill as an Opticalman and the mechanical design of the instrument. The mechanical design is important to the instrument's effectiveness because it controls the stability and cleanliness of the optical elements.

BODY HOUSING

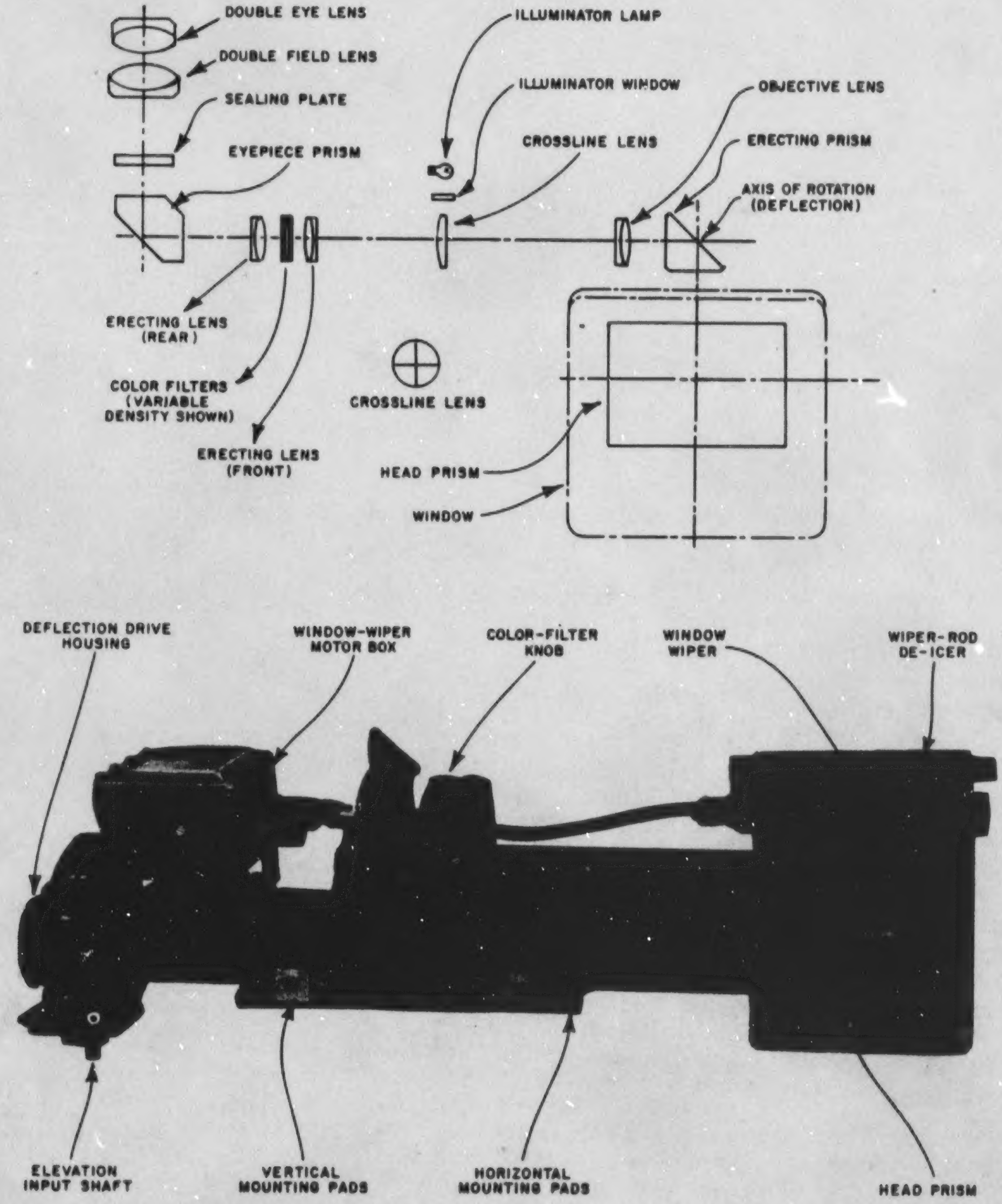
The construction of an instrument housing is influenced by three factors: the location of the instrument when in use; what the instrument is used for; and the arrangement within the housing. For example, the housing of a pair of binoculars is not subjected to the same pressure as a submarine periscope, nor is a binocular's line of sight offset like that of a periscope. Figure 6-1 illustrates a Mk 74 gunsight whose housing is rather small and simple in construction. The housing weighs about 15 pounds and contains 11 optical elements with a line of sight that is deviated 90°.

Figure 6-2 illustrates a Mk 67 gunsight whose housing is large and very complex. The housing of the Mk 67 gunsight weighs about 135 pounds and contains 17 optical elements. These large telescopes, when fixed in position on a gun mount, offset the line of sight about 2 feet and



137.272:.179

Figure 6-1.—Housing features of Mk 74 gunsight.



148.139

Figure 6-2.—The Mark 67 telescope.

enable you to follow fast-moving targets without changing body position. The line of sight is elevated and deflected by rotating prisms that are driven by shafts and gears in the sight mechanism.

Note the differences in the housings in figures 6-1 and 6-2, and note the location of the optical elements in the two gunsights. All of these elements must be positioned and secured in the housing so that they will remain in place under normal circumstances and will not impair the effectiveness of the instrument through unwanted movement.

Material

The material used to construct the body housing is selected with reference to the specific instrument. If the instrument is to be hand held and portable, the material must be lightweight yet strong enough to withstand the shock and abuse it may be subjected to. Cast aluminum and magnesium alloys are usually used for binocular bodies and some portable straight line telescopes.

Gunsight telescopes are mounted directly on turrets and gun mounts where they receive considerable shock. Most housings of gunsight telescopes are made from cast bronze or steel alloys which are strong enough to support and protect the optical and mechanical components of the telescope. The material specifications for a telescope housing are shown on the appropriate drawing, and an Opticalman should know the type of material he will be working with before he attempts any repairs to the housing.

Arrangement

The location of the optical and mechanical components of an instrument is a prime factor in determining how a housing must be constructed.

Figure 6-3 is a cutaway view of the Mk 102 Mod 2 telescope, showing the complexity and importance of a housing arrangement. Refer to this figure often as you study the description that follows.

The telescope housing assembly is cast bronze and finish-machined with great precision. It is open at the front and back. The front of the housing is closed by a window and the rear by a metal cover plate. The interior of the housing is divided by an irregular vertical wall into an optical chamber and a servochamber. The gastight optical chamber is in front of the dividing wall and the watertight servochamber is to the rear. A square box shaped section rises from the top rear of the housing to position and support the headrest assembly, optical tube, and focusing assembly. The housing is cast with four mounting pads, two on each side, which provide a vertical mounting surface, and four mounting pads on the bottom which provide a horizontal mounting surface. Both of these mounting surfaces are precision machined to provide accurate alignment of the telescope on the gun mount.

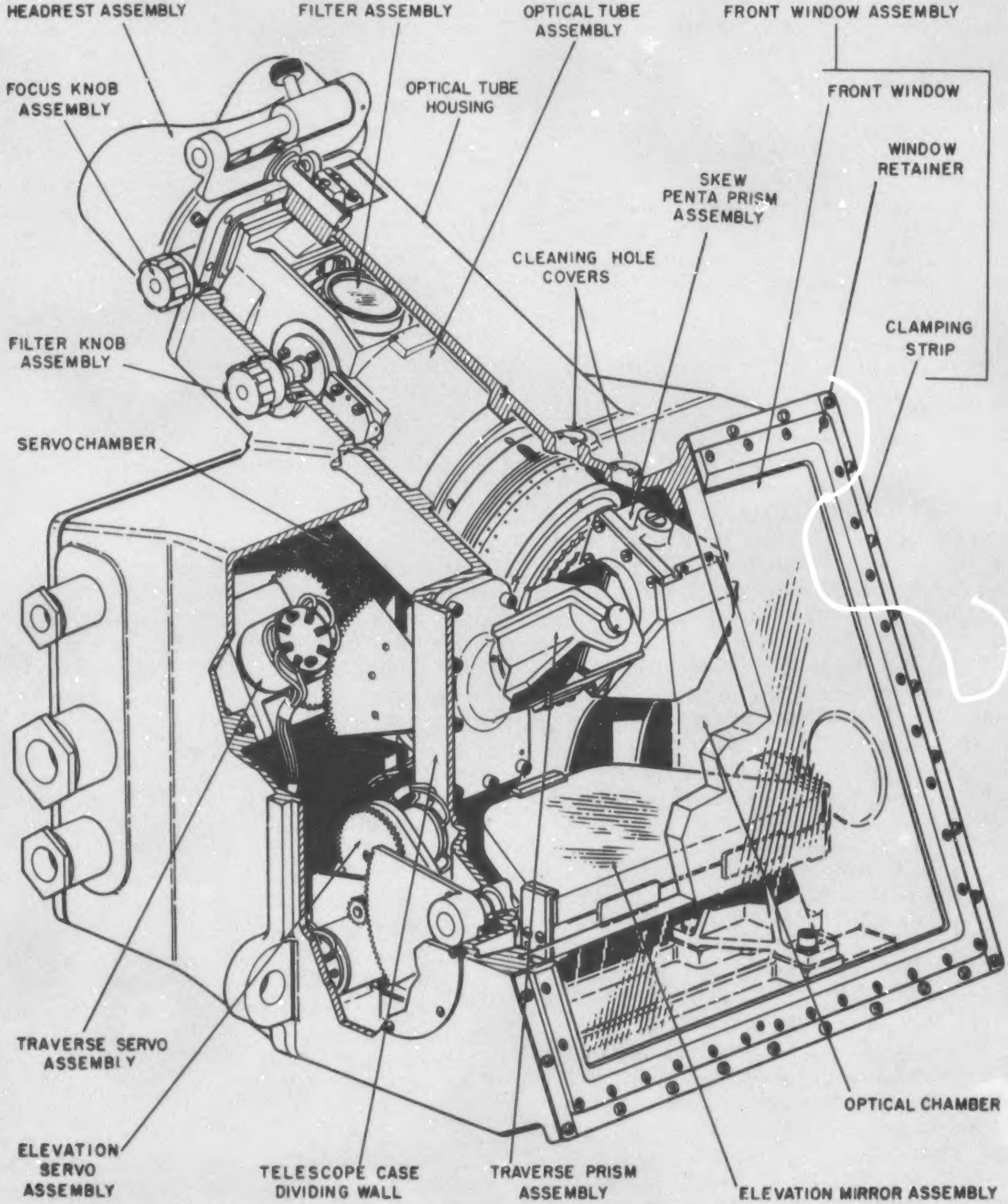
The front window of the telescope is secured by a window retainer and sealed by two gaskets. Stuffing tubes on the right side of the housing allow for passage of electrical cables without losing the watertight seal in the servochamber. The focusing knob and filter knob are sealed by a packing gland where the shaft passes through the housing.

The optical tube assembly is a brass cylinder which houses the objective lens, filter assembly, and reticle in position within the body housing.

The elevation mirror, traverse prism, and skew penta prism assemblies are positioned in the optical chamber by brackets. Two servoassemblies mechanically connected to the mirror and traverse prism allow the line of sight to be elevated and deflected.

Access and Adjustment

You have seen how the design of a housing is affected by the positioning of the instrument components. Another problem that a designer must consider is accessibility. A body housing must be made in such a way that all of the parts enclosed in the instrument can be assembled and



137.518

Figure 6-3.—Telescope Mk 102 Mod 2; cutaway view.

adjusted in a convenient manner. A number of access holes and cover plates are provided for this purpose. The number of openings in any instrument housing is always kept to a bare minimum because each opening is a source for gas to escape and moisture or dirt to enter the instrument.

SHADES AND CAPS

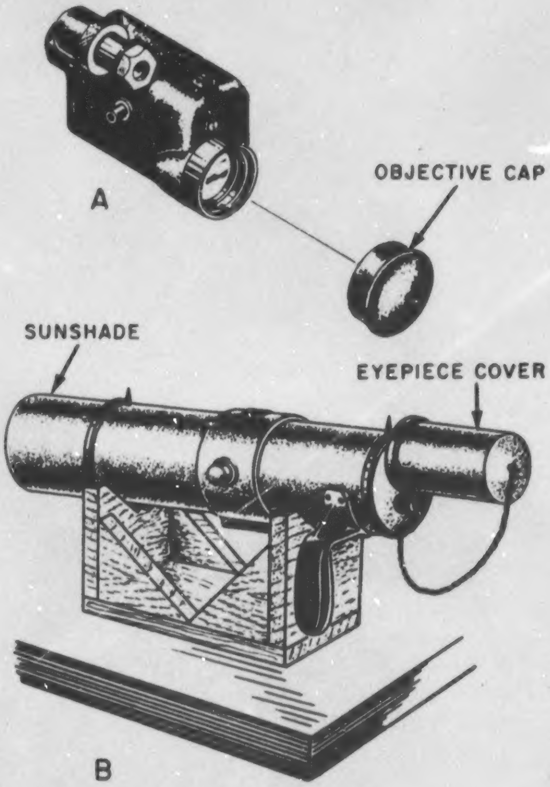
When an optical instrument is not is use, it should be placed in a case that will protect the exposed optical elements. If the instrument is mounted in such a manner that using a case is not feasible, some other form of protection is provided.

Lens Caps

A lens cap is a very effective and convenient way to protect an eyelens or objective lens. These caps are made of metal with a friction fit over the area to be protected, or they are threaded onto the telescope. Part A in figure 6-4 illustrates a slip-on objective cap for an azimuth telescope, and Part B shows a threaded cover for a ship's telescope eyepiece. When a ship is at sea, the external optical surfaces are exposed to saltwater spray, stack soot, direct sunlight, and grime which will damage optical elements very easily. For these reasons, the protective caps should always be in place when the instrument is not in use.

Sunshades

An optical instrument that is used extensively in sunlight has a sunshade to reduce glare from sunlight directly striking the outer face of the objective lens. Sunshades, as illustrated in figure 6-4, are usually tabular sections of metal fitted around the objective. A sunshade also protects the objective from falling rain and heat from the sun that would harm the cement used to cement elements of an achromatic objective.



37.2

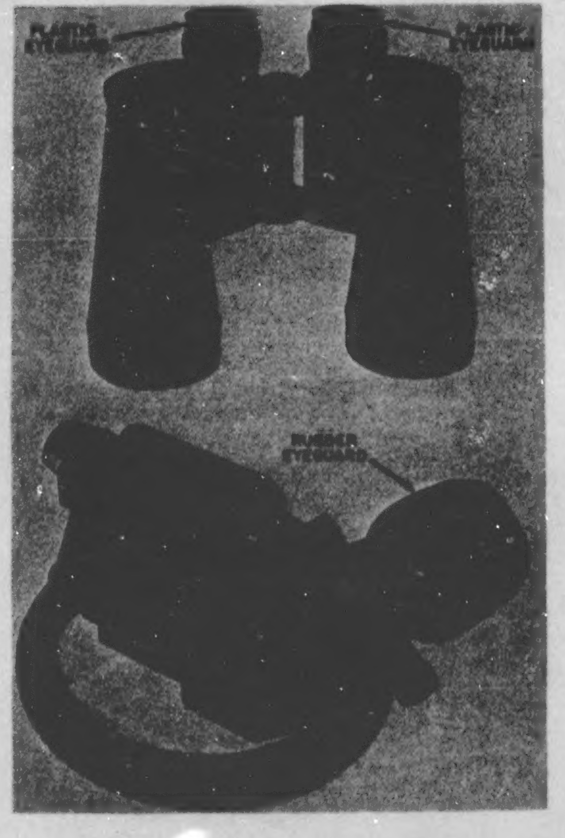
Figure 6-4.—Lens caps.

Eye Guards

Eye guards similar to those illustrated in figure 6-5 are used extensively on optical instruments. These guards, made of plastic or rubber, protect the observer's eye from gunfire shock or similar disturbances. An eye guard also maintains proper eye distance and keeps out stray light rays.

DIAPHRAGMS

Diaphragms are rings of opaque material placed in an optical system so that the passage of light is limited to their center. When a diaphragm is used in this manner, it is referred to as a stop. Refer to figure 6-6 as you study the various stops in the following sections.



37.1:45.39

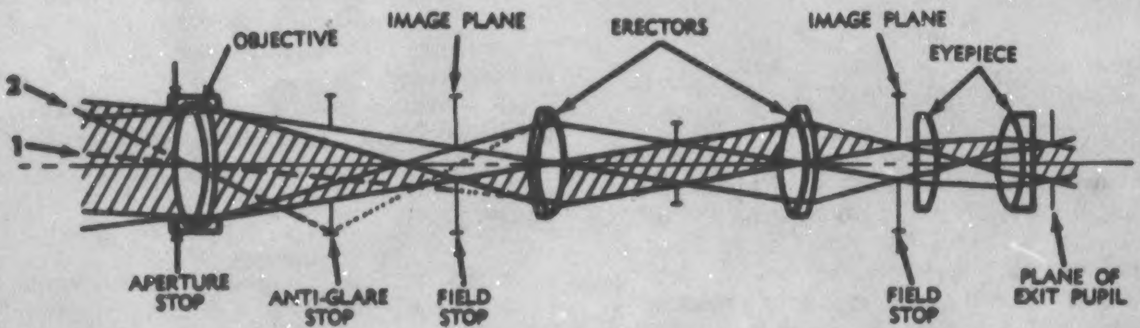
Figure 6-5.—Eye guards on instruments.

Field Stop

A field stop is a diaphragm that limits the field of an instrument to the area which is most illuminated. A field stop is placed at the image plane and helps to produce a sharply focused image by eliminating the peripheral rays which cause poor imagery because of aberrations. Placing the field stop at the image plane not only limits the field, but also sharply defines the edge of the field and prevents the observer from viewing the inside of the instrument. When a field stop is used at each image plane, the second and succeeding field stops are larger than the image of the first so that slight inaccuracy in size or positioning will not conflict with the sharply defined image of the first.

Aperture Stop

An aperture stop is a diaphragm that limits the size of the aperture of a lens. In most telescopes this is usually the objective lens mount or retainer ring as there is no reason for reducing the size of the aperture of the single compound objective lens used in such an instrument. A stop in close proximity to a single compound objective will reduce only the illumination and exit pupil size without reducing lens aberrations. In the event the objective of an instrument is so complex that two or more separate lenses are used, an aperture stop between the elements may reduce aberrations.



173.164

Figure 6-6.—Diaphragm locations.

Antiglare Stops

Antiglare stops are diaphragms placed in optical instruments within the focal length of the objective to prevent marginal rays from reflecting off the interior of the instrument and causing glare. Antiglare stops are finished with nonreflecting paint or oxide coatings.

In straight line telescopes, the stops can be merely washers or disks with a hole in the center. In the construction of binoculars, the prisms shelf is designed to act as a stop for stray light.

MOUNTING OPTICAL ELEMENTS

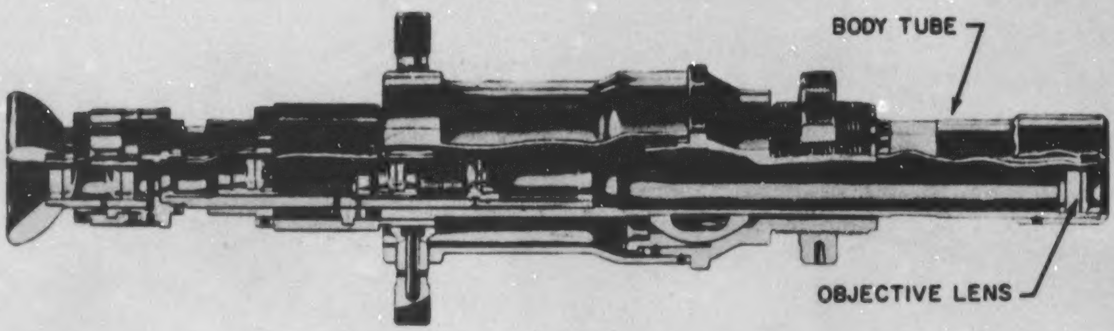
After the designer of an optical instrument has decided where an element must be positioned, he must also solve the difficult problem of designing the proper mount for the element. The lens or prism must be held securely in place without strain which would cause a distorted image or could break the element. If the element is to be adjustable, he must design the mount so that it can be adjusted without looseness or play. The following discussion covers the most common mounts with which you will be working as an Opticalman.

LENS MOUNTS

After a lens has been ground and polished to the proper curvature, it is ground on the edge to its final diameter. Since the edge of the lens is used to position it in its mounting, the optical axis of the lens must coincide with its mechanical axis. Occasionally, it is possible to machine the housing of an instrument so that a lens can be mounted directly in the housing, as with the objective lens of the Mk 75 Mod 1 boresight telescope shown in figure 6-7. The objective lens is mounted in a fixed position at the end of the body tube against a seat ring and held in place by a retaining ring.

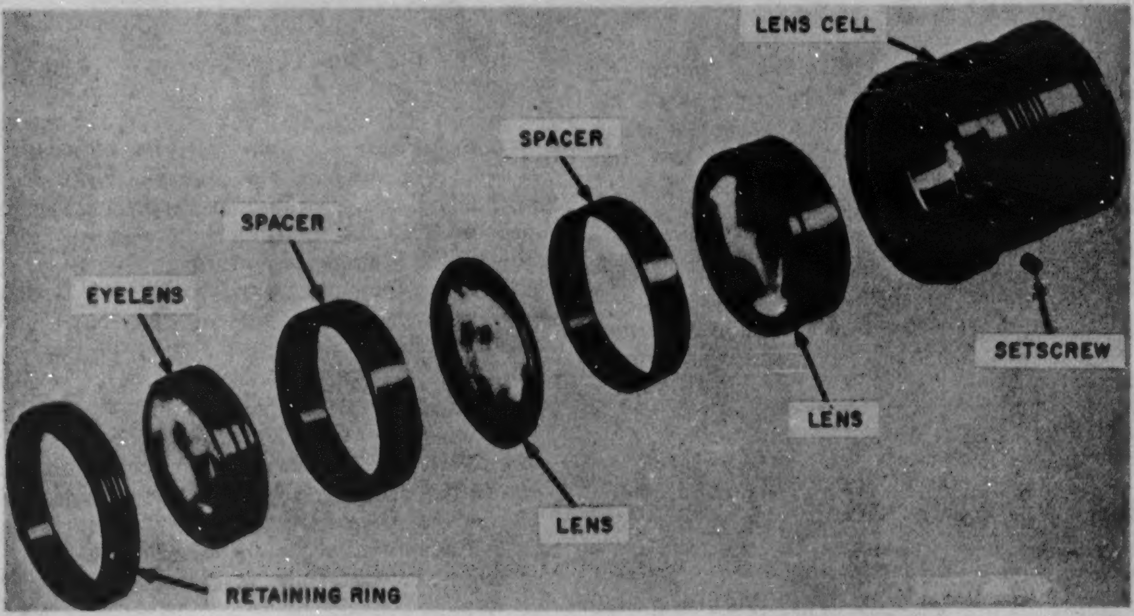
When two or more lenses are positioned near each other, the designer uses a lens cell similar to that shown in figure 6-8. The lens cell is made of tubular metal precisely machined to hold the lenses, separated by spacers, in a predetermined position. The spacers are machined with a bevel where they make contact with the lens to provide a snug fit with no sharp edges to mar the lens. The optical and mechanical parts are then secured in the cell by a retaining ring. Lenses mounted in a cell can be adjusted and placed in the instrument as an assembly.

An **adjustable mount** (fig. 6-9) is often used to mount **a single lens** in an instrument so that it may be axially adjusted during assembly. The lens is fitted snugly against a shoulder in the mount and held in place by a retainer ring. The mount is externally threaded so that it can be



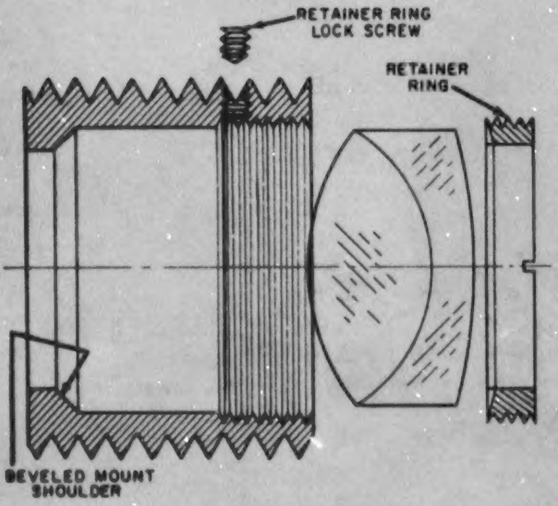
84.207

Figure 6-7.—Cutaway view of a Mk 75 Mod 1, boresight telescope.



137.165

Figure 6-8.—Lens cell, lenses, spacers, and retaining ring.



136.166

Figure 6-9.—Adjustable lens mount.

screwed into the telescope housing to its proper position; it is locked in place by a lock ring or setscrew.

Retainer Rings

In our discussion of lens mounts, we have frequently illustrated and referred to retainer rings. You have seen how they are used to hold a lens in a mount and how they are used to secure a mount in place. Every instrument that you work on in the Navy will have retainer rings. They are very important to an instrument. When a retainer comes loose, the lens is also loose and the instrument's effectiveness is impaired or lost.

You will be working with rings which range from small and delicate to large and cumbersome. All rings must be handled carefully so as not to damage the fine threads or distort their shape. Most retainer rings and other threaded mechanical parts are locked in place by a setscrew or locking compound that hardens when dry, such as shellac. BE VERY SURE THAT YOU REMOVE ALL SETSCREWS AND

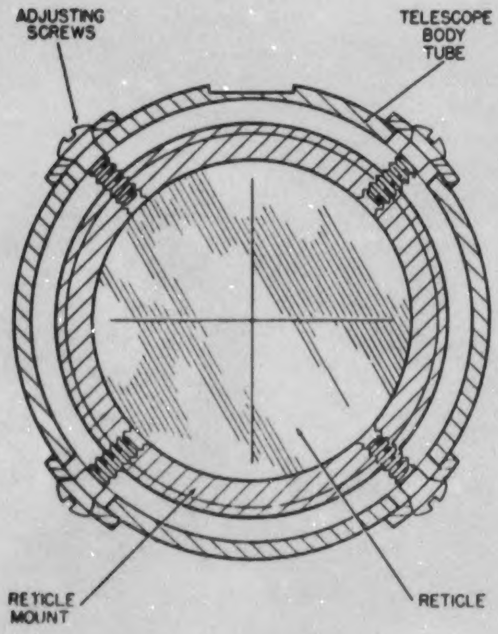
LOCKING COMPOUNDS BEFORE TURNING THE RING. If not, you will damage the threads on the mount and the retainer, causing added repair work or loss of the part. Note the setscrews which lock the retainer in figures 6-8 and 6-9. Not all locking screws are so prominently located, so examine the parts carefully for hidden lock screws.

Screw Adjusting Mounts

Occasionally an element must be adjusted after the instrument has been assembled. In such cases you will find a screw adjusting mount similar to that illustrated in figure 6-10. This mount has four adjusting screws at 90° intervals for adjusting horizontally and vertically. The adjusting screws extend through the telescope body and can be either a slotted head (illustrated) or a thumb screw type. By letting out on one screw and taking up on the other, you can position the element with great accuracy. Be careful when tightening the screws so that no undue strain is placed on the mount or element.

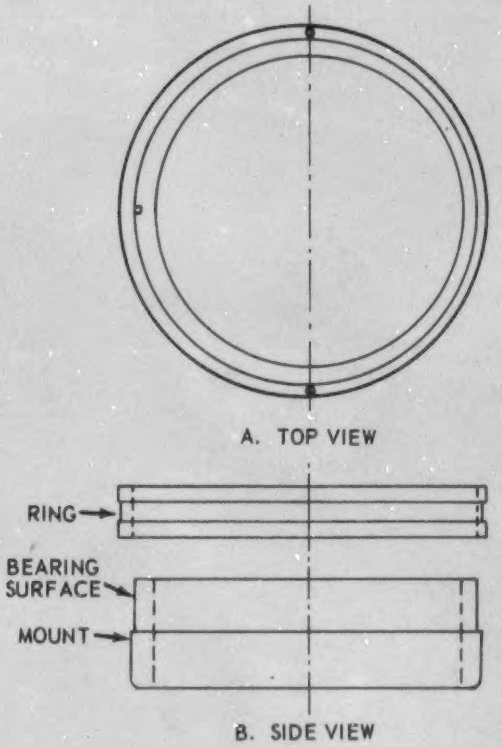
Eccentric Mount

You have learned that the optical axis of an instrument must coincide with its mechanical axis if the instrument is to be in alignment. To assure alignment, lenses are sometimes placed in an adjustable eccentric mount to allow movement of the lens and its optical axis in a plane perpendicular to the axis of the instrument. Figure 6-11 illustrates the eccentric objective mount of a binocular; refer to it as you read the following description. The lens mount has a machined bearing surface that offsets it from the mechanical axis of the mount (eccentric). A ring whose inner and outer



137.520

Figure 6-10.—Adjustable reticle mount.



137.521

Figure 6-11.—Eccentric lens mount assembly.

surfaces are eccentric to each other is placed over the bearing surface of the mount to act as a bushing to hold the assembly in the binocular body. By rotating the entire assembly or by rotating the outer ring around the mount, you can move the optical axis of the lens to any desired point within a relatively large area. You can obtain some additional movement by rotating the objective lens in its mount since most lenses have some inherent eccentricity. The objective assembly is then locked in place by a setscrew or retainer ring, or both.

PRISM MOUNTS

As with other optical elements, a prism in an optical instrument must be correctly positioned with respect to all other elements in the system. The problem of positioning a prism is compounded by the bulkiness and the varied shapes of prisms. Since practically all lenses are round, designers use tubular mounts for most lenses. However, prism mounts must be individually designed to fit the shape of a particular prism. Space does not permit a full description of all prism mounts used in Navy instruments, but we will briefly explain a few.

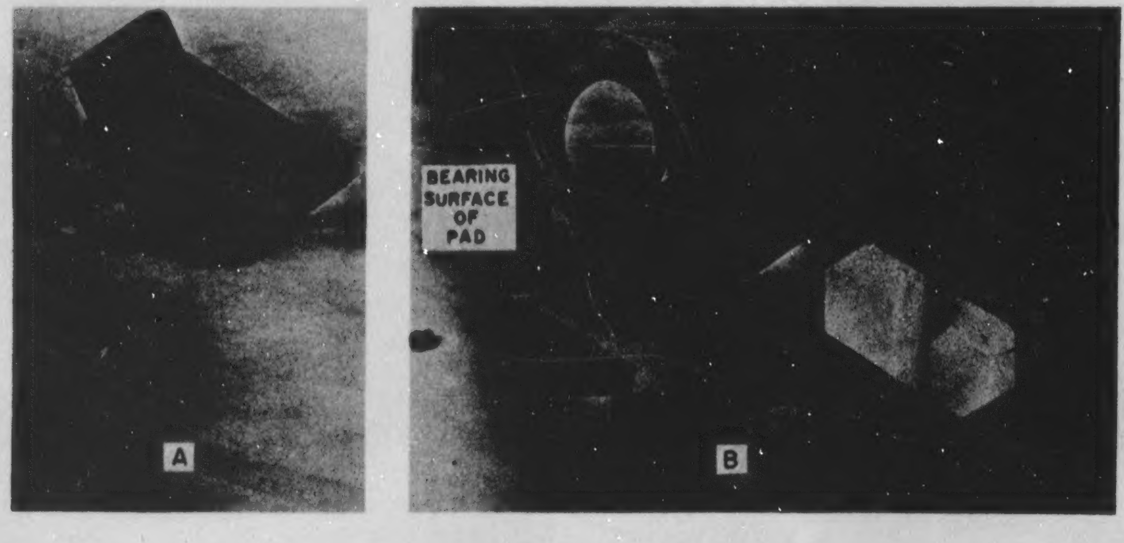
Roofedge

The roofedge prism mount, shown in part A of figure 6-12, consists of a right-angled bracket on which the prism rests. Shoulders ground on the frosted sides of the prism act as mounting surfaces which are used to secure the prism in the bracket.

Two prism straps, one on each side, are placed against the prism shoulders and secured by screws to the bracket. The bracket is fastened to the telescope body with four screws which can be loosened to adjust the prism mount. Part B of the illustration shows disassembled parts.

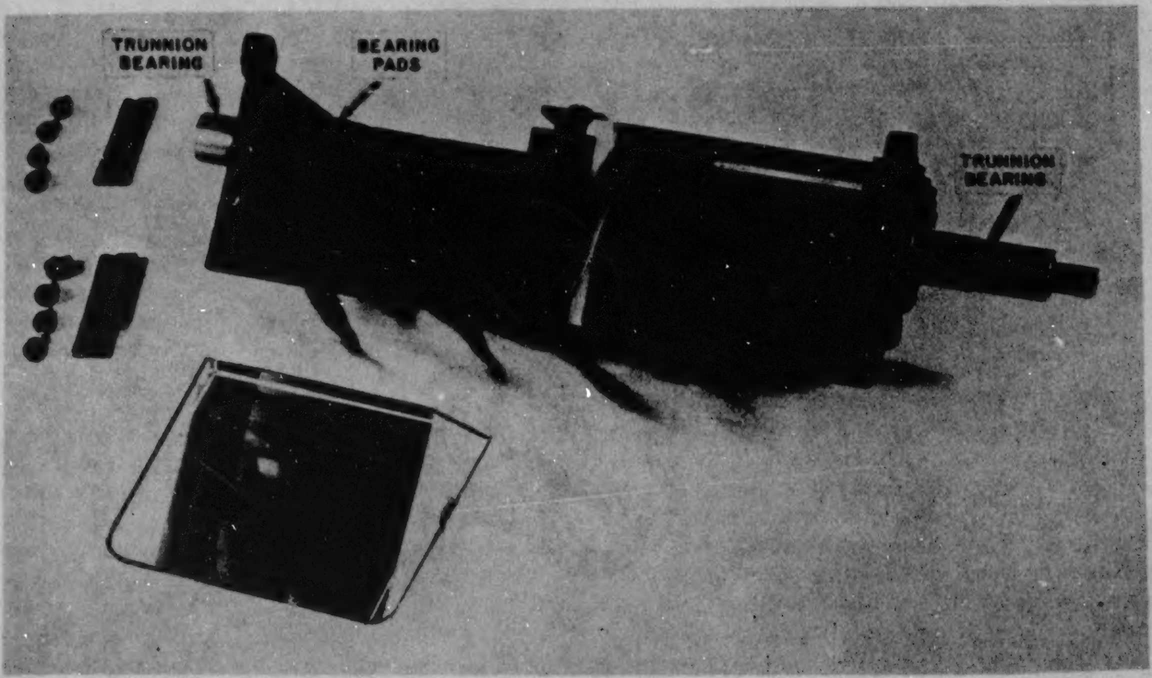
Right-Angled

Mounts for right-angle prisms vary in design in accordance with needs. One mount (fig. 6-13) holds the silvered, or reflecting, surfaces of prisms securely in place and properly aligned on bearing pads which prevent the surfaces from touching the base of the mount. Four prism straps, two on each side, hold the prisms in position. The straps also contain bearing pads which help to keep the prisms properly aligned without chipping during the shock of gunfire.



137.171

Figure 6-12.—Roof-edge prism mount.



137.172

Figure 6-13.—Right-angled prism mount.

Porro Prism Mounts

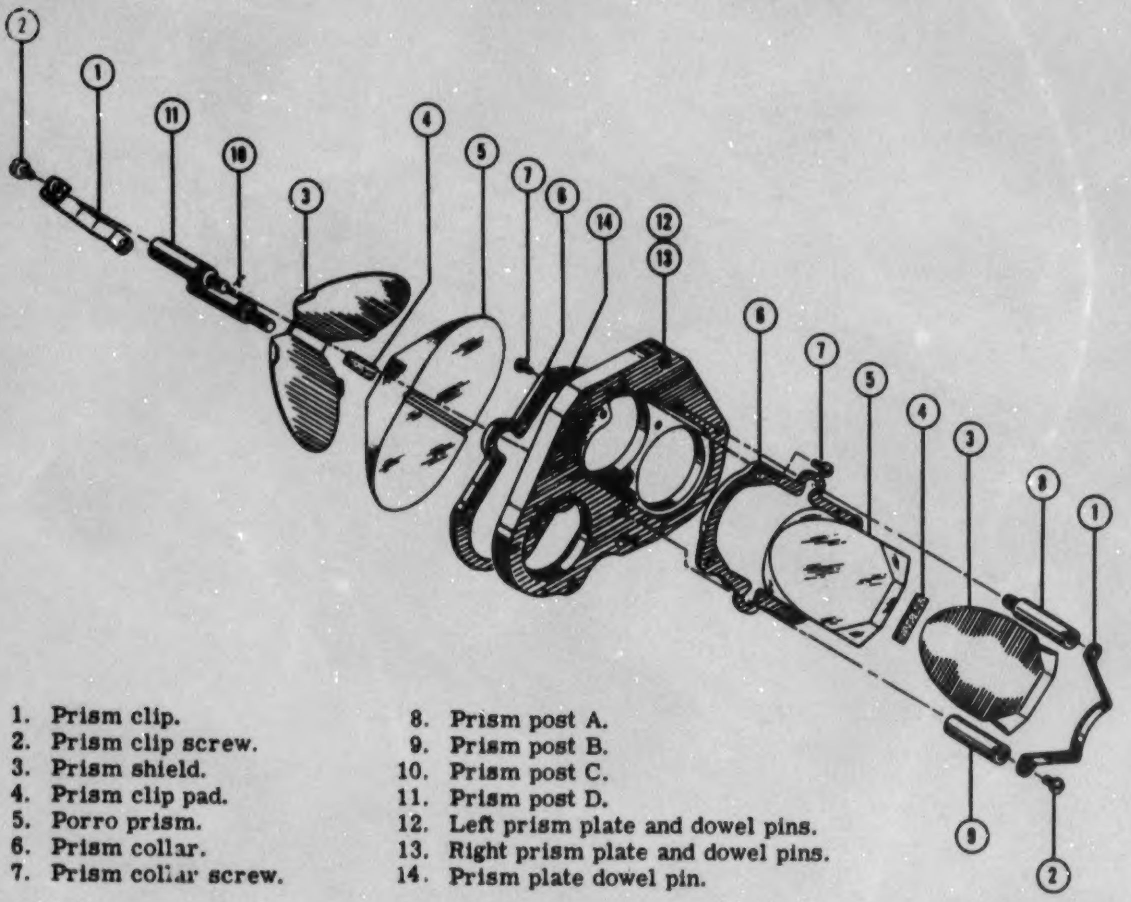
A porro prism mount (fig. 6-14) consists primarily of a flat, metal plate shaped to the interior of a telescope body. It is machined to hold one prism on each side of the plate. The hypotenuse surfaces of the prisms are mounted parallel to each other, and they are set over holes machined in the plate to allow light to pass from one prism to the other.

To maintain the APEX surfaces of the two mounted prisms at 90° angles to each other, a rectangular metal adjustment ring (prism collar) is placed snugly around each prism. If the two prisms are NOT at 90° angles to each other, LEAN is created in the prism cluster. Lean means that an object viewed through the prism cluster appears to lean at an angle when compared with the actual object.

Each prism is secured to the mount with a spring clip or prism strap, pressed against the apex of the prism. The strap itself is secured to two posts, one on each side of the prism; the posts, in turn, are screwed into the prism plate. A metal shield placed over each prism under the prism strap prevents stray light from entering the other prism surfaces. These shields must not touch the reflecting surfaces of the prisms; if they touch, total internal reflection does not take place and some of the light is refracted through the reflecting surface and absorbed by the light shields.

FOCUSING ARRANGEMENTS

The majority of focusing arrangements with which an Opticalman comes in contact are eyepiece assemblies, since most instruments must be adjustable to the individual observer's eye.



1. Prism clip.
2. Prism clip screw.
3. Prism shield.
4. Prism clip pad.
5. Porro prism.
6. Prism collar.
7. Prism collar screw.
8. Prism post A.
9. Prism post B.
10. Prism post C.
11. Prism post D.
12. Left prism plate and dowel pins.
13. Right prism plate and dowel pins.
14. Prism plate dowel pin.

137.170

Figure 6-14.—Porro prism mount.

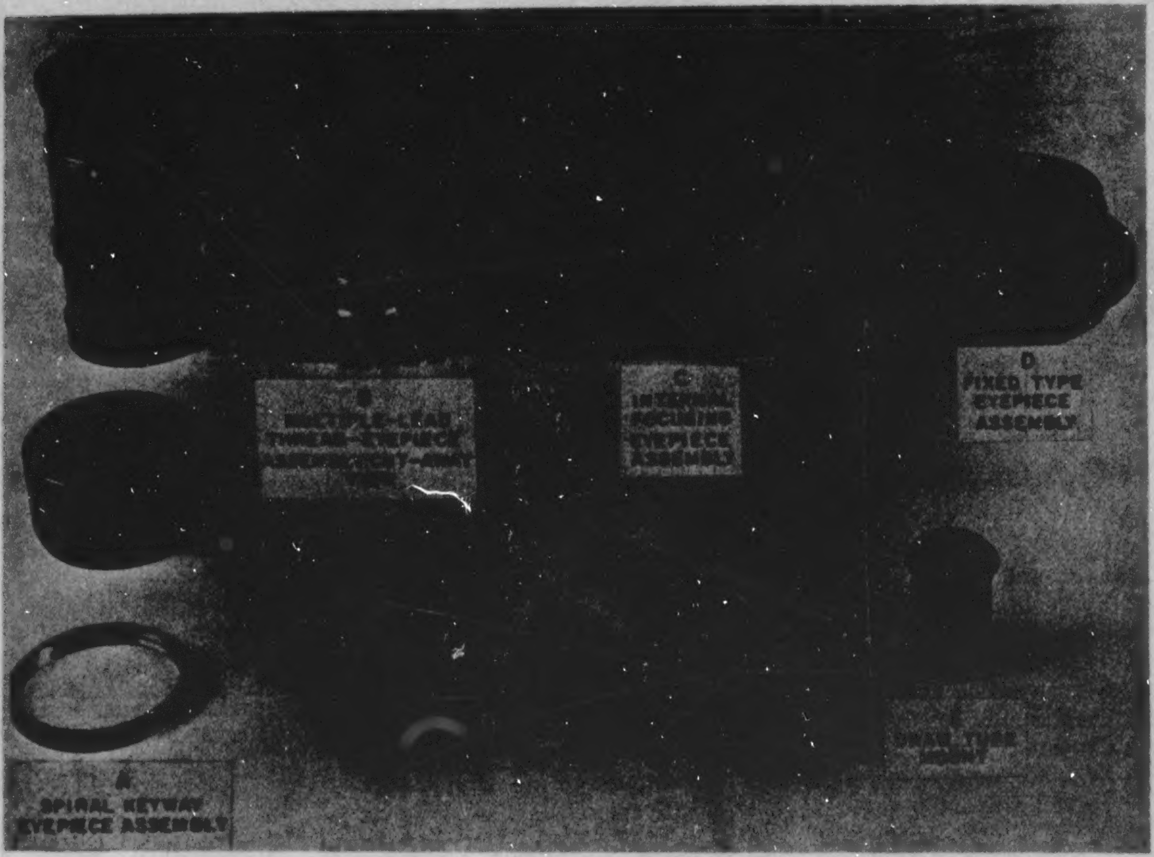
Lenses in an eyepiece usually are secured in a tubular type mount. The field lens and the eyelens may be fastened separately, each with a retainer ring, or they may be secured together by the same retainer ring with a spacer placed between the field lens and the eyelens to hold both at the correct distance from each other.

The distance between the reticle and the eyepiece in an optical instrument must be adjusted to the observer's eye so that the reticle and image of the object are sharply defined, eliminating eye fatigue. To provide this adjustment, the lenses (two or more) of the eyepiece are mounted in a single lens cell, or tube, whose distance from the reticle (also focal plane of the objective) can be adjusted by a rack and pinion, a draw tube, or by rotation of the entire eyepiece during adjustment of the focus.

Some of the focusing arrangements used on eyepieces are shown in figure 6-15.

Draw Tube

A draw tube focusing arrangement (fig. 6-15E) consists of a metal tube which contains the lenses and their retainer ring. The tube is



137.173

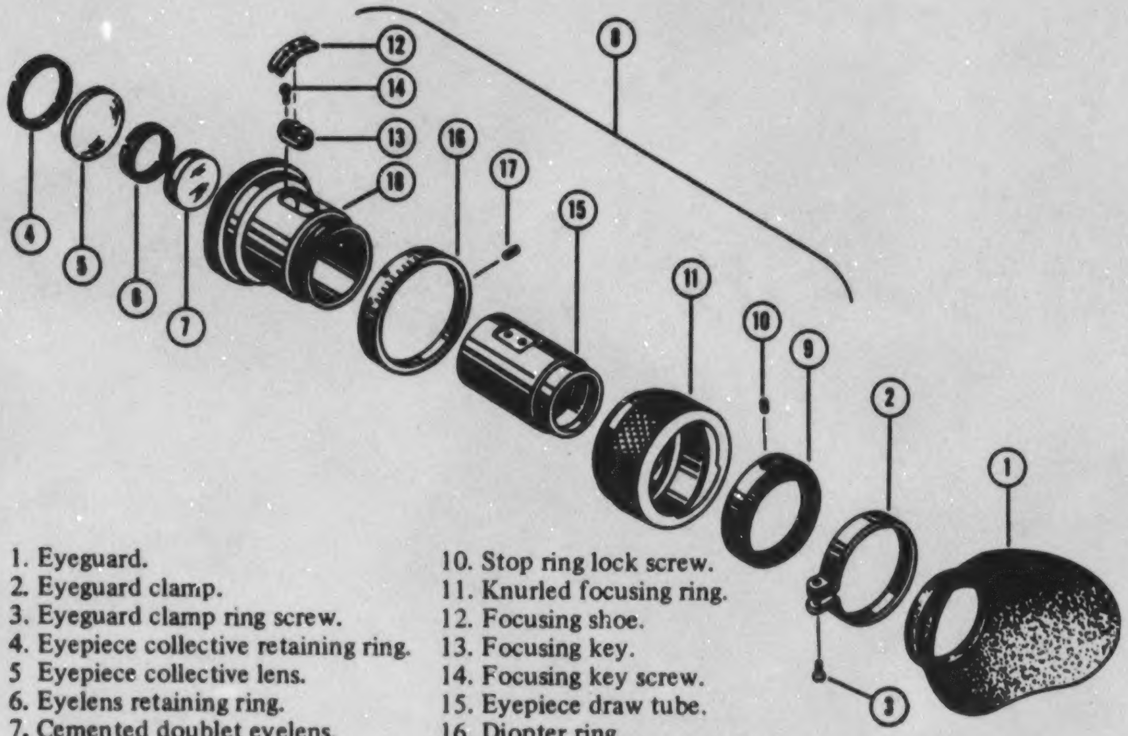
Figure 6-15.—Focusing arrangement.

focused manually by sliding it forward or backward in a guide tube at the rear of the telescope body or housing. The draw tube can be secured to the guide tube or withdrawn completely from it. This type of eyepiece focusing arrangement, however, is not widely used by the Navy because the draw tube focus can be disturbed by a slight jar.

Spiral
(Helical) Keyway

A spiral keyway focusing arrangement (fig. 6-16) is a modification of a draw tube. It is similar in construction to a draw tube with the additional following components: a focusing key or shoe, a focusing ring, a retainer ring, and a diopter-ring scale.

A straight slot, which guides the focusing key, is cut through the eyepiece adapter parallel to the optical axis of the telescope. The focusing key is fastened to the draw tube, protrudes through the straight slot, and holds the focusing shoe which engages a spiral groove or keyway in the focusing ring. The focusing ring turns on the eyepiece adapter but is prevented from moving along the optical axis by a shoulder on the adapter and the stop ring on the opposite side. The diopter ring is mounted on the shoulder of the eyepiece adapter; it is read against an index mark on the focusing ring. Mating parts of this



1. Eyeguard.
2. Eyeguard clamp.
3. Eyeguard clamp ring screw.
4. Eyepiece collective retaining ring.
5 Eyepiece collective lens.
6. Eyelens retaining ring.
7. Cemented doublet eyelens.
8. Eyepiece focusing assembly.
9. Focusing ring stop ring.
10. Stop ring lock screw.
11. Knurled focusing ring.
12. Focusing shoe.
13. Focusing key.
14. Focusing key screw.
15. Eyepiece draw tube.
16. Diopter ring.
17. Diopter ring lock screw.
18. Eyepiece adapter.

137.174

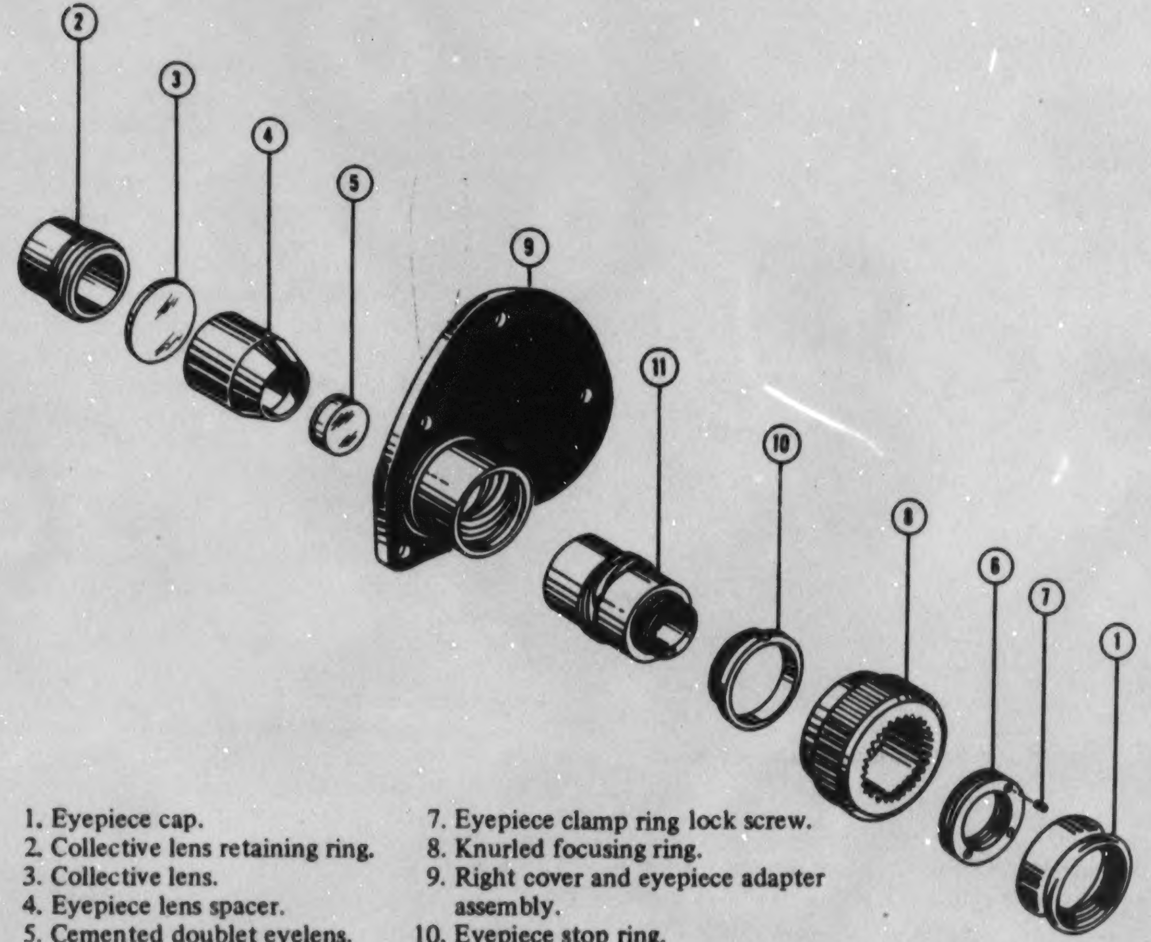
Figure 6-16.—Spiral keyway focusing arrangement.

type focusing arrangement must fit snugly to eliminate lost motion, yet allow smooth movement.

The diopter scale is graduated on either side of 0 diopter to read from plus to minus diopters. The number of plus or minus diopter graduations depends upon the design of the instrument, but it usually runs from +2 to -4 diopters. More adjustment is provided on the minus diopter side because most people focus the diverging rays more comfortably. When the focusing ring is turned either way, the focusing shoe follows the spiral keyways and moves the draw tube in or out to focus the eyepiece. As the operator, you focus the eyepiece to your eye and note the diopter scale reading; you can save time by adjusting to that reading each time you use the optical instrument.

Multiple Lead Thread

A multiple thread eyepiece (fig. 6-17) is tubular with external multiple lead threads. It screws into a guide tube or eyepiece adapter with matching threads. When the eyepiece cell is screwed all the way into the adapter, it is stopped by the focusing ring. A stop ring is screwed into the top of the adapter, which prevents extraction of the eyepiece cell when the threads reach the stop ring as the mount is screwed all the way out. A focusing ring with a



1. Eyepiece cap.
2. Collective lens retaining ring.
3. Collective lens.
4. Eyepiece lens spacer.
5. Cemented doublet eyelens.
6. Eyepiece clamp ring.
7. Eyepiece clamp ring lock screw.
8. Knurled focusing ring.
9. Right cover and eyepiece adapter assembly.
10. Eyepiece stop ring.
11. Eyepiece lens cell.

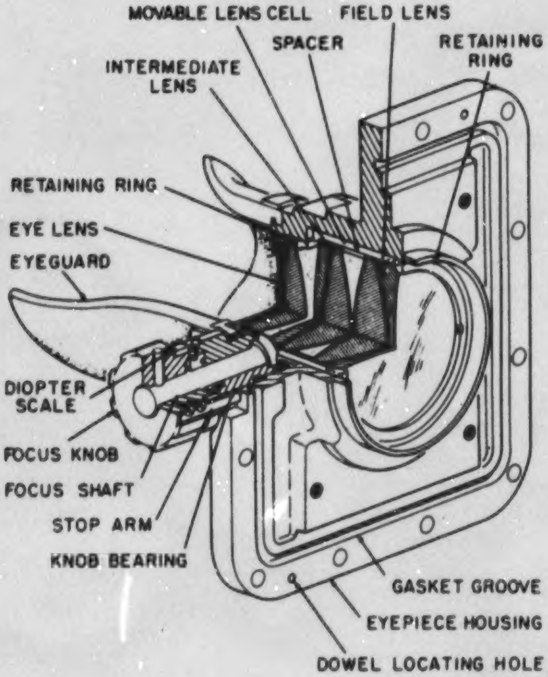
137.175

Figure 6-17.—Multiple-thread eyepiece lens mount.

diopter scale engraved on it is attached to the top of the eyepiece cell and held in place by a clamp ring.

Internal Focusing Mount

An internal focusing eyepiece mount (fig. 6-18) consists of a housing secured and sealed to the rear of the telescope body. The housing contains an eyelens, secured by a retaining ring. A movable lens mount or cell containing the field lens and an intermediate lens is free to move forward or backward when the focusing knob and shaft are activated. As the focusing knob rotates, it turns the focusing shaft and rotates an eccentrically mounted actuating plate which, in turn, slides the movable lens mount toward or away from the eyelens during focusing for individual eye corrections. The dioptric scale is on the focusing knob, and the index mark is on the focusing shaft housing.



137.176

Figure 6-18.—Internal focusing eyepiece mount.

Focusing-type eyepieces are designed to provide fast focusing with minimum turning of the focusing ring, or knob. This design permits the eyepiece (when turned completely out) to stop on the plus side of the diopter scale and to be focused all the way in to the stop on the minus side of the scale, with one rotation (or less) of the focusing ring. Multiple lead thread eyepiece mounts are responsible for this type of focusing. In internal focusing eyepieces, the eccentric plate slides the lens mounts from maximum to minimum throw with a half-turn (or less) of the focusing knob.

The lenses of the spiral keyway and internal focusing eyepieces do not rotate when they are focused, and this is an advantage over a multiple lead thread eyepiece. When multiple lead thread eyepieces are rotated, eccentricity in the lenses or their mounts (if present) causes the image of a target to appear to revolve in a small circle. For this reason, eyepieces with draw tubes which slide in and out without rotating are generally preferred in instruments with reticles. NOTE: The reticle must be superimposed on the same spot of the target all the time, regardless of the manner in which the eyepiece is focused. If the eyepieces or lens mounts rotate with eccentricity in a telescope which has a reticle, the image of the target appears to move under the reticle image in a small circle.

One advantage internal-focusing eyepieces have over spiral keyway and multiple lead thread eyepieces is that they can be sealed to prevent entrance of foreign matter and moisture. Telescopes with these eyepieces can be submerged in water, because they will not leak when properly assembled.

Spiral keyway and multiple lead thread eyepieces cannot be submerged under water because they also breathe during focusing; that is, when you focus them in, they compress the air within the telescope and force it out through joints and loose fittings. NOTE: Some telescopes have a small hole near the eyepiece mount which enables the air in them to escape freely. When you focus these eyepieces out, they draw air and dust into the telescope. This breathing action can be caused also by changes in atmospheric pressure or temperature changes (day to night, for example). As time passes, dirt and moisture collected on the optical elements of the telescope diminish or obliterate vision through the instrument.

FIXED EYEPIECE MOUNT

A fixed-type eyepiece (fig. 6-15), as the name implies, is fixed in position and cannot be focused for individual eye correction. The eyepiece mount may consist of a housing which contains the eyelens, separator, field lens, and the retainer ring secured and sealed at the rear of the telescope body. The eyepiece housing may also be part of the main telescope body. If the eyepiece housing is part of the main telescope body, the lenses and the spacer slide into the eyepiece housing from inside and are secured in place with a retaining ring.

Because this eyepiece cannot be focused for individual eye correction, the light rays which leave it are slightly divergent with a value of -3/4 or -1 1/2 diopters. This fixed minus diopter setting is used because the majority of operators set focusing eyepieces slightly on the minus side of the dioptric scale.

BEARINGS

When a shaft is mounted in a device to hold it during rotation, friction develops at the contact point between the shaft and the device. Friction develops heat. Therefore, friction produced in a shaft housing must be kept to a minimum for satisfactory performance and longer life of the shaft. Devices which reduce the amount of friction produced by shafts in their housings are called bearings.

Except for simple types, optical instruments have many moving parts. Movement of these parts, however, must be so restricted that motion takes place only in the direction desired. Movable parts of an optical instrument must therefore be supported and retained by some suitable means, so that friction-free movement in a specific direction may be obtained.

Before we get into the discussion of different types of bearings, it is a good idea to explain the different types of loads which bearings must carry:

NORMAL LOAD: A load applied toward and perpendicular to the bearing surface.

RADIAL LOAD: A load directed away from a surface, the opposite of a normal load. Rotation of a wheel or object on an axis is an application of radial load.

AXIAL LOAD: A load directed along the axis of rotation or surface of an object.

ANGULAR LOAD: A load which is a combination of the other loads just described.

Bearings are generally classified as sliding surface and rotational (sometimes called rolling contact bearings).

Sliding Surface Bearings

A sliding surface bearing usually has a stationary member which forms the base on which its moving part slides. A lathe, for example, has this type of bearing in the holding and guiding of the carriage and tailstock on the lathe bed. Sliding surfaces are not always flat; they may be square, angular, spherical, or circular. The piston and cylinder bore of an internal-combustion engine constitute a circular sliding surface bearing.

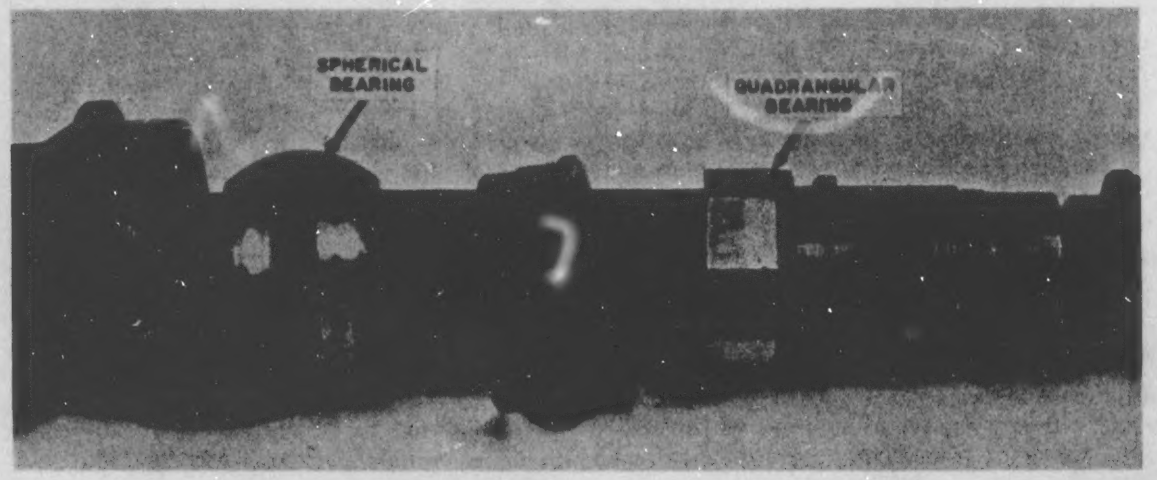
Square and spherical sliding surface bearings are used to mount some of the smaller gunsights in order that they may be easily boresighted (aligned with the gun). Refer to figure 6-19 which shows these two bearings as used on an instrument. The spherical bearing is secured in its mating mount which is firmly attached to an adapter or gun mount. The spherical bearing holds the front of the instrument securely and at the same time allows radial motion of the body.

The square bearing (quadrangular) provides a surface for bearing pads and adjusting screws which can accurately lock the instrument in any desired position. The bearing surfaces in this instance are subjected to normal loads by four adjusting screws in an adjusting-screw mount. Each adjusting screw exerts pressure on its respective bearing surface. By loosening and tightening opposing screws, as necessary, you can boresight the telescope. Adjusting-screw mounts are also good for holding and adjusting reticle mounts.

Although not a sliding surface bearing, the square bearing is used as a locating bearing surface, with little if any sliding motion exerted upon it. When accurately machined, a square bearing is used as a bearing pad for holding large gunsights in gun mounts and directors and for locating and holding parts inside optical instruments. During overhaul of a gunsight telescope, bearing pads are reference surfaces for aligning optical elements.

Rotational Bearing

A rotational bearing generally has a stationary member for holding the rotating



137.178

Figure 6-19.—Cylindrical bearing and square bearing in an instrument assembly.

member. The stationary member is called the sleeve. The rotational member is usually in the form of a shaft, whose precision-finished surfaces are called trunnions.

Trunnion bearings (fig. 6-13), such as those on the ends of a MK 61 telescope right-angled prism mount, are used on many kinds of telescopes to keep the optical axis of a telescope or prism mount in a true vertical plane during elevation or depression of the line of sight.

Ball Bearings

Because rolling friction is much less than sliding friction, precision ball bearings are used extensively in optical instruments. Precision ball bearings in self-contained units are classified in accordance with design. Differences in design in ball bearings are generally not apparent externally. In making a design of these bearings, the outer race, the inner race, and the steel balls (which roll between the races) must be taken into consideration.

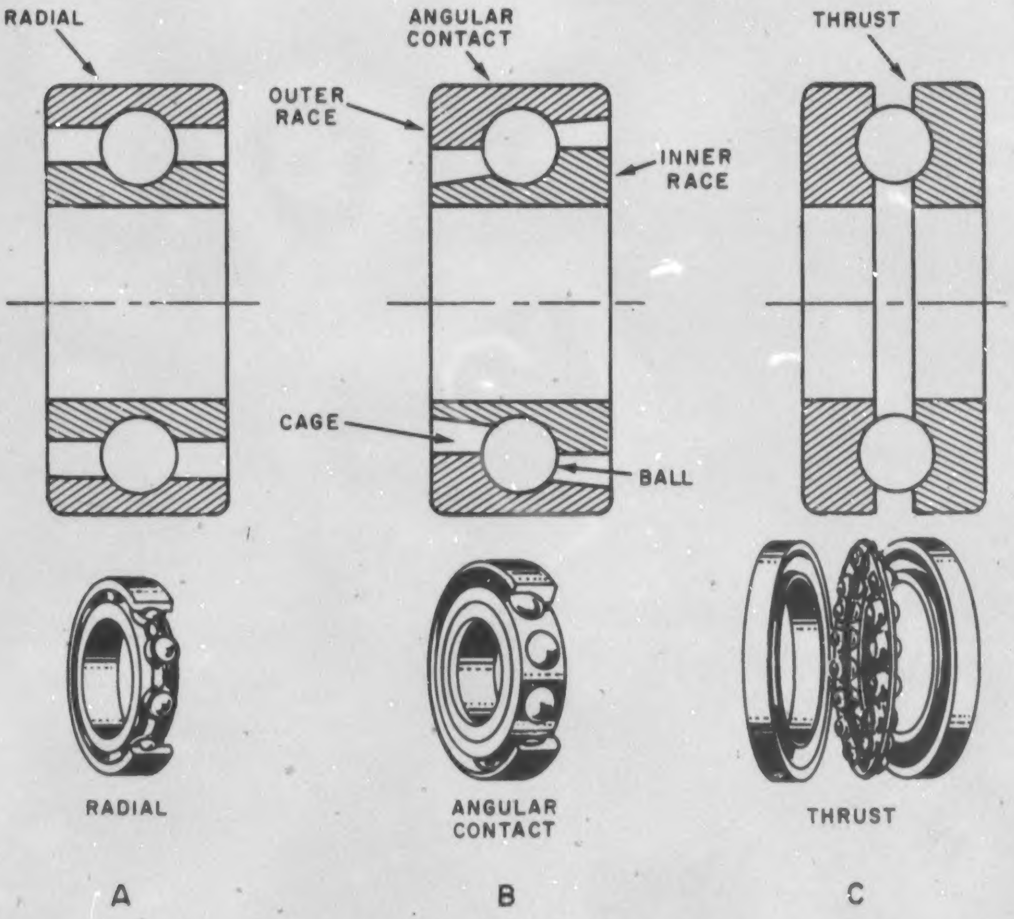
As you study the most common designs of self-contained precision ball bearings in the following paragraphs, refer to figures 6-20 and 6-21 to determine their differences.

Radial ball bearings (fig. 6-20A) are designed to carry loads applied to a plane perpendicular to the axis of rotation in order to prevent movement of the shaft in a radial direction. Thrust ball bearings (fig. 6-20C) are designed to take loads applied in the same direction as the axis of the shaft in order to prevent endwise movement.

Radial and thrust bearings are therefore designed to carry loads in a specific direction: perpendicular or parallel to the axis of supported shafts.

An angular ball bearing (fig. 6-20B) supports an angular load—a load which has components of radial and axial thrust—and it is exemplified by the bearing in the front wheel of a bicycle. Angular ball bearings are normally used in pairs, in a manner which enables the angular contact surfaces of one bearing to oppose the corresponding surfaces of the other. This arrangement of bearings provides a technique known as PRELOADING, which removes what is called give or softness before the bearings are subjected to their normal loads.

The principle of preloading is illustrated in figure 6-21. Preloading can be obtained (and normally is) by subjecting the inner races to a thrust directed axially toward the angular contact sufaces of the outer races.



77:66

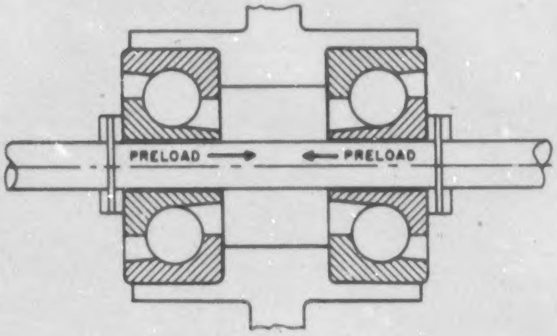
Figure 6-20.–Different types of ball bearings.

In some cases, individual precision steel balls are used as a bearing between two parts; the parts themselves act as the bearing races with the desired number of steel balls rolling between them. Such a bearing is used between polaroid filter plates in optical instruments to secure smooth and free rotation.

CAUTION: Dry metallic surfaces under an appreciable load, though smoothly machined, will not slide over each other without abrasion; they must be kept covered CONTINUALLY with an approved lubricant. If properly lubricated, precision-made ball bearings wear very little. When wear does occur in ball bearings, replace them. Adjustment is impossible.

OPTICAL INSTRUMENT GEARS

An instrument designer must know what type of gears to use for a specific function in order to provide the type of motion and speed required. Because you must work with these



137.180
Figure 6-21.—Preloading produced by pairs of angular ball bearings.

gears in optical shops, knowledge concerning the basic types will be beneficial to you.

Spur Gears

The spur gears shown in figure 6-22 are from a Mark 74 gunsight. Spur gears are used more than any other type of gear in optical instruments to transmit power from one shaft to another.

5.22.1
Figure 6-22.—Types of spur gears.

Teeth on spur gears vary in size (in accordance with requirements) and are stated in terms of PITCH, or DIAMETRAL PITCH (number of teeth per inch of pitch diameter). A spur gear with 16 pitch and a pitch diameter of 1 inch has 16 teeth, and so forth.

Speed ratios between shafts having spur gears is important and is defined as the reciprocal of the ratio of the quantity of teeth of the two gears. For instance: if two mating gears have 40 teeth and 10 teeth respectively, the ratio is 4 to 1. The speed of the 10-tooth gear will be 4 times that of the 40-tooth gear.

Metals generally used in small spur gears are brass, aluminum, and steel; but cast iron is widely used in large spur gears. Spur gears, however, are also made of nonmetallic substances.

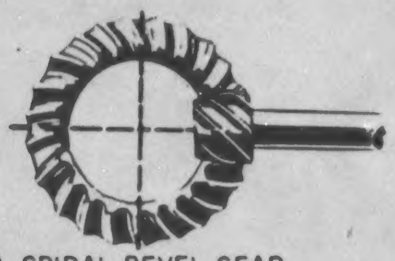
Bevel Gears

Bevel gears used in optical instruments can be put on shafts which intersect at desired angles, provided the angle of the teeth is correct in relation to the shafts.

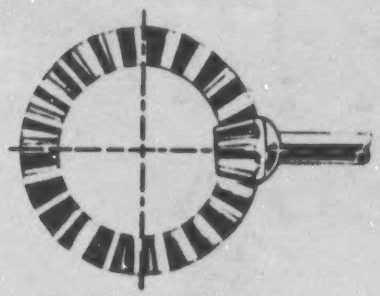
When one component of a pair of gears which mesh together is bigger than the other (A and B in fig. 6-23), the bigger component is usually called the GEAR and the smaller component is called the PINION.

Bevel gears are made with straight or curved teeth, but they CANNOT be interchanged with spur gears. By using different size bevel gears as shown in figure 6-23, you can obtain a different speed ratio, as desired. When these gears are the same size, they are called MITER GEARS. NOTE: If lapped pairs of bevel gears are used in an optical instrument, almost perfect quietness of operation is obtained.

The shape of bevel gears, especially those with spiral teeth, causes them to exert considerable thrust. For this reason, the end of a shaft which contains the gear is generally supported by an angular ball bearing, and the other end has a radial ball bearing.



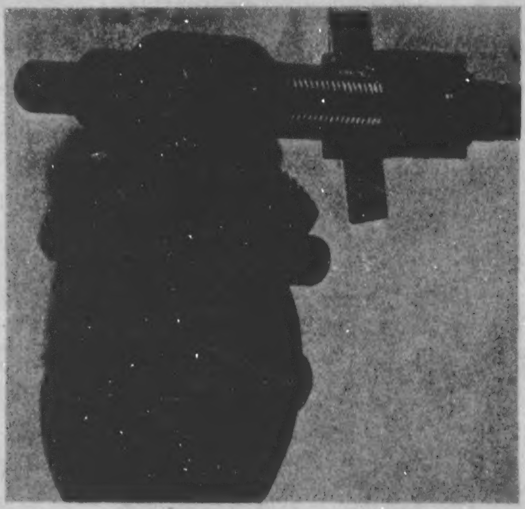
A. SPIRAL BEVEL GEAR



B. BEVEL GEAR

81.195

Figure 6-23.—Types of bevel gears.



5.22.9

Figure 6-24.—Sector gear and worm.

Worm and Sector Gears

Study figure 6-24. The top part is called a WORM, and the bottom part is called a SECTOR GEAR.

If a worm has only one continuous thread, it is called a SINGLE-THREAD worm. More than one thread may be cut on a worm. A worm with two continuous threads is called a DOUBLE-THREAD worm; a worm with three continuous threads is called a TRIPLE-THREAD worm. On a worm with a single thread, lead and pitch are equal, but the lead is twice the pitch on a double-thread worm and three times the pitch on a triple-thread worm. Therefore, if a single lead worm is used, one revolution of the worm advances the sector one tooth. With a double or triple-thread worm, the sector will advance two or three teeth with each revolution of the worm.

As you can see from figure 6-24, the rotation of the sector is limited to approximately 90°. If the sector were made with teeth all the way around (full 360° rotation), then the arrangement would be called a worm and worm gear.

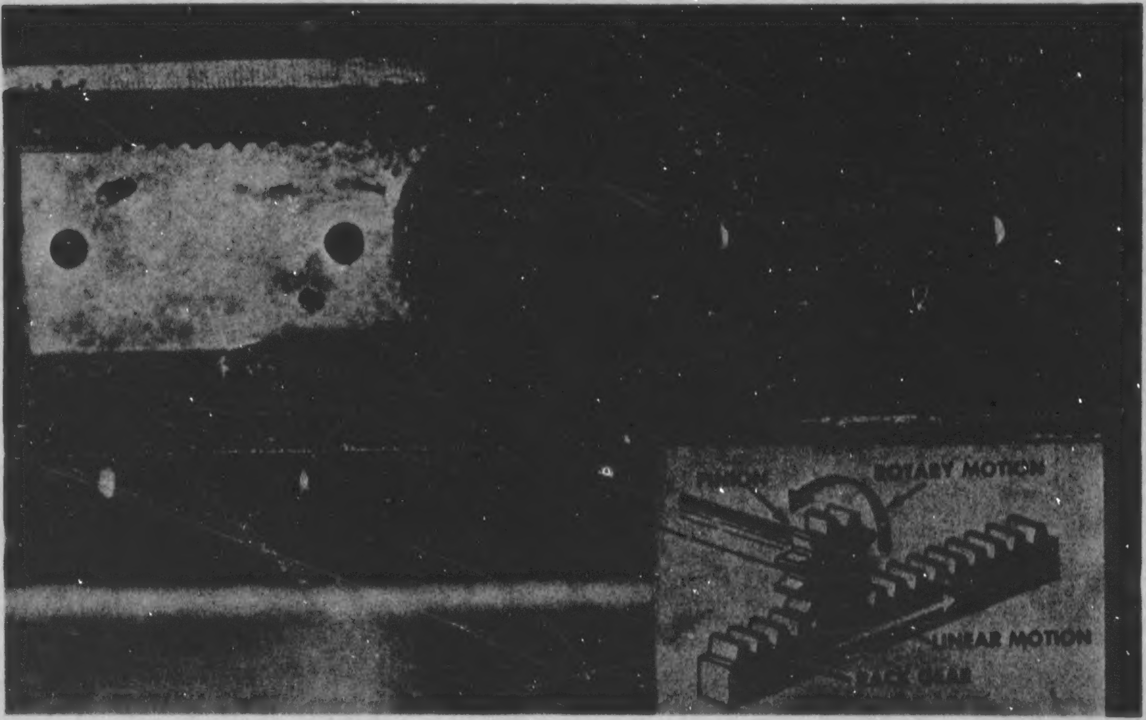
HELICAL GEARS

Helical gears are closely related to worm gears in function and general arrangement, except that mating helical gears are usually of the same thickness, and teeth are cut at a 45° angle to the axis of rotation.

With a worm and sector or worm and worm gear, the worm is the driving member; the worm causes the gear or sector to revolve, but not vice versa. With helical gears, even those of different diameters, either gear can drive the other.

Rack and Pinion

Some optical instruments use a rack and pinion such as the one illustrated in figure 6-25. The rack gear moves in a linear motion, as indicated; and it is simply a straight bar into which the gear teeth have been cut. The pinion, of course, moves in a rotary motion.



5.22.13

Figure 6-25.—Rack and pinion.

INSTRUMENT SEALING METHODS

To maintain the cleanliness of the optics in optical instruments, the instrument bodies are sealed to keep out moisture and dirt. All optical instruments are sealed but they are not necessarily waterproofed to stand submersion in water.

All openings in optical instruments are sealed with sealing compound or gaskets. A combination of both is often used. The gaskets may be made of rubber, plastic, or lead.

Instruments are waterproofed by using gaskets on all outside joints or, where a gasket cannot be used because of physical limitations, sealing compound. A well-designed waterproof instrument will have gaskets for all seals except for such small, nonflexing joints as a setscrew going through a body.

The primary job of waterproofing or sealing must be done by the designer. Your responsibility as a repairman is to do your job of sealing with care and precision. The standard techniques for performing waterproofing and sealing operations are set forth in the following paragraphs.

SEALING COMPOUND

Sealing procedures for using rubber compounds fall into two categories: sealing optical elements and sealing mechanical parts. The following procedure applies to sealing lenses and windows. The shape is not important. The common element in all classes of this work is the joint of glass to a metal shoulder in a mechanical part.

The sealing compound used is a jelly-like rubber called RTV which sets into a tough, flexible consistency after being exposed to air for a short time. The RTV (available in black, clear, or grey) comes in tubes with a tapered spout. To make a small bead of sealer, cut off the tip of the spout; to make a longer bead, cut off more of the spout.

1. Place a bead of RTV around the area to be sealed. Excess sealer may prevent optics from seating evenly; too little compound at any point will provide a poor seal.
2. Set the optical element in its mount and press down firmly and evenly all the way around.
3. Replace the retainer. For lenses, tighten the retainer ring snugly. Window retainers (usually rectangular) must be tightened by taking up on opposing screws much as you would for tightening cylinder head bolts.
4. Wipe away excess sealer.

> CAUTION: Optics must not be cocked when the retainer is tightened. They will either break, cause distortion in the image, or fail to seal properly. Firm pressure is sufficient.

Optics sealed with sealing compound will appear tight because they are stuck in the compound. However, they will come loose eventually if the retainer is not snug.

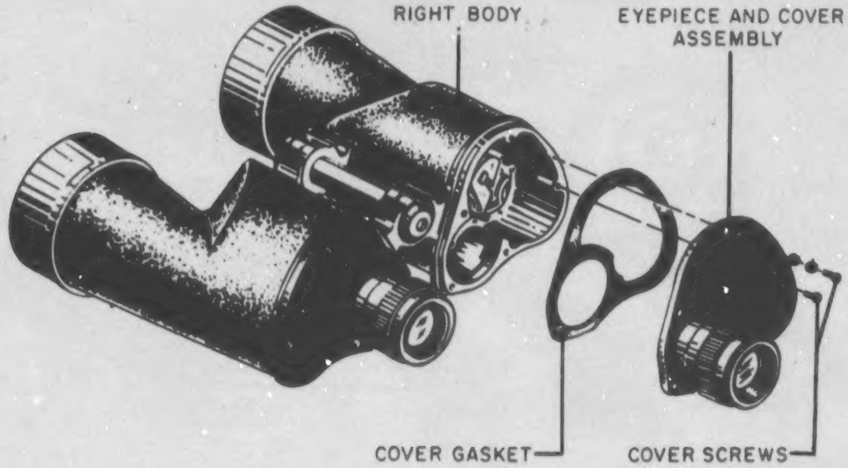
The sealing of mechanical parts is not a series of step-by-step operations which can be used in all situations. Closing an opening is the basic purpose of sealing, yet each sealing operation must be studied to determine where the opening is and where to apply the sealing compound. Your objective is to form a neat, satisfactory seal and hide the joint if possible.

PREFORMED GASKETS

The most widely used method for sealing an optical instrument is preformed gaskets. They provide the best seal and are used extensively when an instrument must be watertight or pressuretight. Three types of preformed gaskets are used on Navy instruments; flat gaskets of irregular shape as shown in figure 6-26 and round O-rings and flat gaskets as shown in figure 6-27.

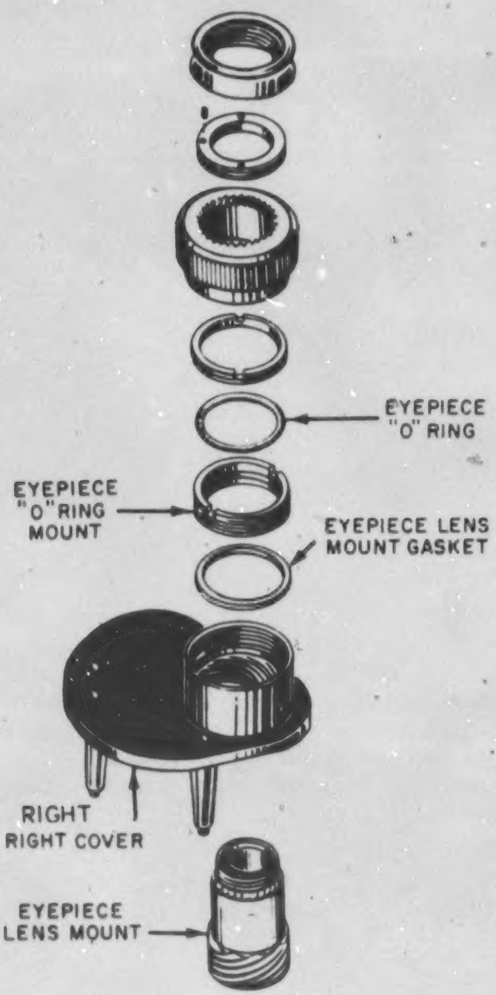
When sealing an instrument with flat gaskets you must strictly adhere to the following rules:

1. Use the proper gasket for each joint.
2. Use new gaskets. They go far to assure a watertight instrument.



137.467

Figure 6-26.—Eyepiece and cover assembly gasket.



137.523

Figure 6-27.—Eyepiece O-ring seal.

3. Be sure the gasket surface of the part and the gasket itself are clean. Foreign matter may cause a gap in the seal.

4. Place the gasket in the correct position and make sure it will be flat against the part it is sealing.

5. Tighten the parts to be sealed sufficiently to squeeze the gasket; however, excess pressure may cut the gasket.

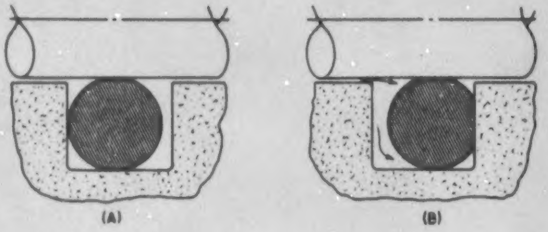
6. Examine a gasket joint, if possible, after it has been reassembled to check the gasket for proper position.

O-RINGS

An O-ring seal on an optical instrument is engineered to meet a set of standards that apply to all O-ring seals. All O-rings are molded and trimmed to extremely close tolerances in cross-sectional area, inside diameter, and outside diameter. An O-ring is generally fitted into a rectangular groove machined in the mechanism to be sealed. The dimensions of the O-ring groove (seat) and the size of the O-ring must be exact if the seal is to function properly. Unlike a flat gasket which seals as a result of the squeeze from the two parts, the O-ring seals as a result of distortion caused by pressure. Notice figure 6-28 which shows the proper installation of an O-ring. The clearance for the O-ring in its seat is less than the free outer diameter, and the O-ring is slightly squeezed out of round (fig. 6-28).

When pressure is applied, the O-ring moves away from the pressure into the path of leakage, thus completely sealing the passage (fig. 6-28B). The greater the pressure applied, the tighter the seal becomes. When the pressure is decreased, the resiliency and elasticity of the seal returns the O-ring to its natural shape. Due to age and temperature variations, O-rings can become set (loss of resilience) and fail to perform as a seal.

O-rings are an excellent means for sealing shafts projecting through an optical instrument body housing and for sealing windows, inspection plates, and various other fittings attached to optical instruments. When O-rings



137.524

Figure 6-28.—Properly installed O-ring.

are used, the seating surfaces must be clean and absolutely free of dents or scratches. The O-ring must be in perfect condition, and the correct O-ring for each sealing application must be used.

Because of the requirements for perfect seating surfaces, O-rings are removed and installed with wooden dowels or with special brass tools. Careful use of these tools will prevent damage which causes unnecessary waste of time and material.

Although an O-ring may appear perfect at first glance, slight surface flaws may exist. These are often capable of preventing satisfactory O-ring performance.

By rolling the ring on an inspection cone or dowel, you can check the inner diameter surface for small cracks, particles of foreign material, and other irregularities that will cause leakage or shorten the life of O-rings. The slight stretching of the ring when it is rolled inside out will help to reveal some defects not otherwise visible. Make a further check of each O-ring by stretching it between your fingers, but be careful not to exceed the elastic limits of the rubber. Following these inspection practices will prove to be a maintenance economy. It is far more desirable to take care in identifying and inspecting O-rings, than to repeatedly overhaul components because of faulty seals. If an O-ring has any defect, discard it.

The problem of positively identifying the correct O-ring to use is made more difficult because many of these seals appear identical in size and color, but are intended for different applications. For this reason, O-rings are sealed in envelopes with a label which indicates part number, size, and life expectancy. Always keep O-rings in their original package until ready for use, and determine exactly which seal to use for each application.

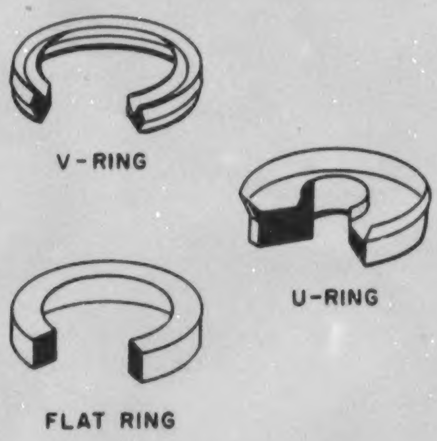
PACKING

As used in mechanics, the term packing refers to the material used to seal an opening where the two component parts move in relation to each other. The type of material used depends on several factors such as temperature, pressure, and type of motion. The most commonly used packing materials for optical instruments are natural rubber, plastics, flax, and synthetics such as neoprene and koroseal. These packing materials come in wide ranges of density, tensile strength, and shape. Packing can be in either preformed shapes, as shown in figure 6-29, or in bulk sheet and spools.

Unfortunately, the length of time that a seal will function properly depends on many factors; many of them unpredictable. Therefore, it is almost impossible to say that a seal will wear out within a specified time.

Each time a component or unit is disassembled the seals should be carefully inspected. If there is any doubt as to their condition, they should be replaced. In most cases, automatic replacement of the seal is standard procedure. The manufacturer's recommendations, along with the previous experience of the personnel repairing the unit or component, should be the main criteria for determining when to replace a specific seal. Installation of seals should be carried out as specified in the maintenance manual, manufacturer's publication, or *Naval Ships' Technical Manual.*

It has been found from experience that packings deteriorate with age. Therefore, knowing and understanding packing shelf life will save you many hours of unnecessary toil in repacking a unit and having it still leak because the packing was defective due to age.



5.35(137A)

Figure 6-29.—Packing rings.

Prior to installing natural and synthetic rubber packings, you must check to determine whether these parts are acceptable for use. All natural and synthetic rubber packing containers are marked to facilitate an age control program. This information is available for all packings used, regardless of whether the packing is stocked on shipboard, at stock distribution points, or furnished as an integral part of a component. Positive identification, indicating the source, cure date, and expiration date must be made of packings.

Cure date means the time the packing was manufactured, and is designated by the quarter of the year and the year of manufacture. Packings manufactured during any given quarter are considered one-quarter old at the end of the succeeding quarter. For purposes of explaining the coding used by manufacturers to designate the cure date, each year is divided into quarters as follows:

First Quarter: January, February, and March

Second Quarter: April, May, and June

Third Quarter: July, August, and September

Fourth Quarter: October, November, and December

Expiration date is the date after which a packing CANNOT be used in service, and time of delivery means the date of acceptance by the purchaser. All packing must be scrapped if not put into use by the time of the expiration date.

Packing is packaged by the manufacturer with a code which indicates year and quarter of manufacture and the expiration date.

EXAMPLE 1076 Expiration Date: March 78

This code indicates the packing was produced during the first three months of 1976, and it should be used before March of 1978.

If a package does not have a legible expiration date, reject it. Likewise, if any packing is not in its original package, do not use it.

Packing should always be stored away from sunlight and in a low-humidity area. Storage area temperatures are also important. A range from 60° to 100°F is usually satisfactory, and in no case should the temperature exceed 125°F.

LUBRICATION

Proper lubrication, using only authorized lubricants, is an important part of optical instrument repair. It is a matter which has been regarded too lightly in the past, the theory being that any grease or oil would do. Experience proves that such an idea is detrimental to the best performance of the instrument.

A lubricant may work perfectly in temperate zones, but stiffen up to the extent of rendering the instrument useless in colder climates. Likewise, a lubricant suitable for use in temperate and cold climates may be entirely unsatisfactory for use in hot regions, where the heat could soften the lubricant to the point of flowing into locations where its presence would impair the functioning of the instrument.

The foregoing facts are particularly of importance in the case of optical instruments where even a very thin film of grease or oil on an optical surface would render the instrument absolutely useless. Since the Navy must use its optical instruments in climates from one extreme to the other, the lubricants used must perform properly under widely varying conditions and in no way impede the functioning of the instrument.

An excessive amount of lubricant is a waste, and often is as bad as, or worse than, not enough. Where closely mated parts that require only a very thin film of lubricant are concerned, an excess can introduce errors in the reading of the instrument.

The primary purpose of lubricants in optical instruments is to provide smoothness of action. Lubrication is not used to prevent wear, as is oil in an automobile engine. Thus, only a little will go a long way.

The Navy buys readymade lubricants which have been found to be satisfactory for use on optical instruments. These recommended lubricants are manufactured in different grades adaptable to all types of applications and temperature ranges.

As an optical repairman you should always follow the specifications of technical manuals when lubricating an optical instrument. When specific instructions are not available, ask your shop supervisor which lubricants to use.

APPLICATION OF LUBRICANTS

To apply grease to a surface, use a round hardwood stick which has a chisel point on one end. Dip the end of the stick into the container and pick up a small amount of grease on the end.

Apply the grease to the surface to be greased, smoothing it out with the stick so that the entire bearing surface is covered with a thin film of the grease.

Fit the greased parts together and run them in; or in the case of a screw, turn it in and out a few times to distribute the grease evenly over its entire working area. Then remove the excess grease that is forced out, using the stick to pick off the bulk of the unneeded lubricant.

Wipe grease from areas where none should remain, using a clean, lintless cloth moistened with solvent.

Keep the oils in small individual instrument oil cans fitted with a cap for protection against dirt. Greases must be kept in clean jars or cans and kept covered when not in use to prevent contamination by dust, grit, and dirt. All containers should be properly labeled with the name of the lubricant and also the material specification number.

CHAPTER 7

MAINTENANCE PROCEDURES—PART I

This chapter provides information on repair and maintenance of optical instruments. We will stress the importance of careful handling and cleanliness of the instruments you will maintain and the tools you will use.

Optical instruments are expensive, precision-built devices, and we cannot overemphasize the care in maintaining them. If an instrument is handled roughly or dropped, the shock may result in misalignment or breakage of the optical and mechanical parts. When this happens, you have only one choice—REPAIR. You must unseal the instrument, disassemble it, make repairs, reassemble, and collimate. This amounts to a lot of work caused by thoughtlessness and negligence in handling.

Optical instruments are shipped in specially constructed containers designed for adequate protection during transportation. When you receive optical instruments in the shop, check the containers for damage and cleanliness; then, if you do not start to work on the instrument at once, stow them in clean storage cabinets or spaces provided for them. CAUTION: When you must move an instrument from one location to another, if possible, move it in its container.

Most containers for optical instruments have catches or locks to secure the instruments in position. When you put an instrument into its container, place it gently in position and carefully close the lid. DO NOT TRY TO FORCE AN INSTRUMENT INTO ITS CONTAINER NOR SLAM THE COVER SHUT. If the instrument does not slip easily into its case, check for an extended drawtube or something else which is hindering smooth entrance into proper position. CAUTION: Always secure the cover of the container with the catches installed by the manufacturer.

INSPECTION AND TESTING

Your duties as an Opticalman will always call for you to inspect and test optical instruments. The inspection may be held aboard ship before the instrument is delivered to the shop, or you may hold it just before you begin the repair work. In any case, the inspection and testing of an optical instrument are vital, and you should have a thorough knowledge of the instrument and procedures used to inspect it. If an instrument is unfamiliar to you, study all information concerning it in Ordnance Pamphlets (OP's), NavOrd publications, NavShips Manuals, and blueprints. Never attempt to disassemble and repair an instrument until you fully understand it.

INSPECTION OF INSTRUMENTS

There may be occasions when you will be given full responsibility for inspecting all optical instruments aboard a ship. By carefully locating all deficiencies, you will be able to save yourself and your repair activity considerable work.

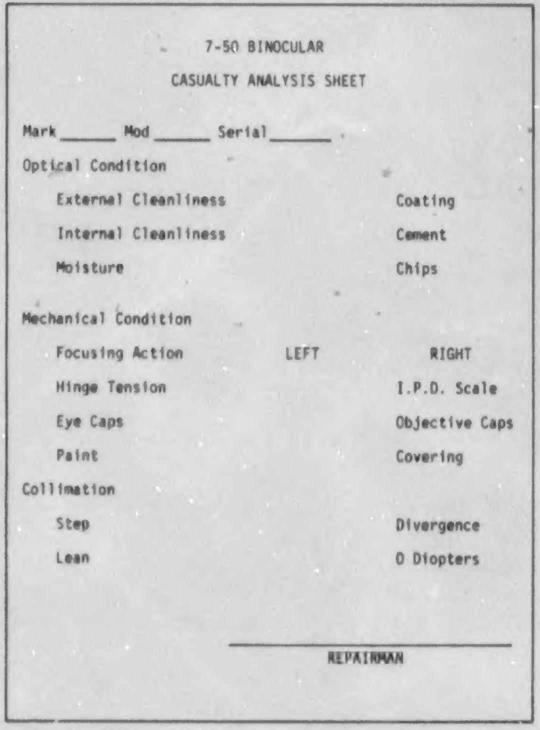
CAUTION: When you inspect an optical instrument in use aboard ship and follow up with minor repairs, do NOT DISTURB the optical system unless it is required.

During predisassembly inspection of an instrument, use a casualty analysis inspection sheet and record all your findings on it. A sample casualty analysis sheet is shown in figure 7-1.

Mechanical Condition

Carefully examine mechanical controls, and check gear mechanisms for slack or excessive tightness. If the instrument is mounted on bearings, check them for dents, gouges, and corrosion.

Try the focusing action of the eyepiece to find out if you can focus it (in and out) without binding or dragging. If binding or dragging exists, the eyepiece is damaged or improperly lubricated.



7-50 BINOCULAR
CASUALTY ANALYSIS SHEET

Mark ______ Mod ______ Serial ______

Optical Condition		
External Cleanliness		Coating
Internal Cleanliness		Cement
Moisture		Chips
Mechanical Condition		
Focusing Action	LEFT	RIGHT
Hinge Tension		I.P.D. Scale
Eye Caps		Objective Caps
Paint		Covering
Collimation		
Step		Divergence
Lean		0 Diopters

REPAIRMAN

137.565

Figure 7-1.—Binocular casualty analysis sheet.

Backlash in the focusing action of an eyepiece is usually caused by a loose stop or retainer ring, but it may be caused by a loose key in a spiral keyway assembly.

Check the mechanical 0 diopter setting of the eyepiece to determine whether the index mark points to 0 diopters when the eyepiece is at midthrow (halfway in and halfway out). The focusing action should be such that the index mark clears all graduations (plus and minus) during full travel of the focus knob.

If the instrument has a ray filter assembly, check the action of the control knob. If rotation of the ray filter shaft does not turn the color filters in or out of the line of sight, the cause is most likely improper meshing of gears or detachment of the gear itself from the shaft. If the shaft does not rotate, it is corroded or bent.

All mechanisms must move freely without binding, slack, backlash, or lost motion. Moving parts should be just tight enough to keep them in proper position.

Check for missing or broken parts—retainer rings, setscrews, and so forth. You can locate loose or broken internal parts by shaking the instrument.

If the instrument is gas sealed, check its gas pressure by attaching a pressure gage to the gas inlet fitting. Then crack the valve screw and read the pressure on the gage. Correct pressure in nitrogen-charged optical instruments is indicated in the manufacturer's technical manual for each particular instrument. If the gage indicates no pressure in the instrument, there is a bad gasket, a loose fitting, or a loose screw. Check for all of these defects when you disassemble a gas-filled optical instrument.

Optical System

Because optical elements constitute the heart of an optical instrument, inspection of the optical system is very important, and you must learn to do this phase of your work well. When you first examine an optical system, you may have difficulty in distinguishing one element from another. With experience, however, you will be able to see each element in the system, and you will be able to pinpoint defects.

The best method for inspecting the optical system of an instrument is to point it toward an illuminated area and look for the following:

Dirt and Dust: Dirt and dust show up as dark spots (specks) on the surface of an optical element.

Chips, Scratches, Breaks: These defects in an optical element show up as bright, star-like specks, scratches, or large bright areas when light is reflected from them.

Grease or Oil: Grease or oil on an optical element is indicated by streaked, clouded, or nebulous areas, with an occasional bright, translucent spot.

Moisture: Moisture shows up as a sharply defined nebulous area, with brilliant reflection or a diffused, clouded appearance when the area is not illuminated.

Fungus or Watermarks: Brown or green patches, or stains, indicate the presence of fungus or watermarks. Deposits of salt cause a grainy, milky color similar to that of frosted glass.

Deteriorated Balsam: Deterioration of Canada balsam used to cement lenses together is indicated by a dark yellow color, or areas between the elements appear milky colored or opaque. When the cement just begins to separate, bubbles or splotches shaped like oak leaves appear between the elements. If there are brightly colored bands or rings (Newton's Rings) between the elements, the lenses are under strain in their mounts, or the elements have completely separated.

Hazy or Clouded Image: Foreign matter on the objective lens, the erectors, or the prisms of an optical system cause a hazy or clouded image.

You can examine color filters in an optical system, if they are within the focal length of the eyepiece, by holding one eye a few inches from the eyepiece and turning the ray filter shaft. Defects on a filter show up when it rotates in and out of the line of sight.

If the field of view (true field) is not perfectly round, there is a loose diaphragm within the instrument or the color filter plate is not properly engaged with the detent ball or roller.

Modern optical instruments have a transparent metallic coating on optical elements to improve light transmission through the instrument. With uncoated optics, there will be an approximate 5% loss of incident light at each air-glass surface due to surface reflection. When magnesium fluoride is correctly applied to optics, this loss of incident light is reduced to about 1%.

The magnesium fluoride coating is deposited on optics to a depth of 1/4 the wavelength of yellow-green light. This amounts to four millionths of an inch (.000004). You do not need to actually measure this coating when you perform an inspection. If you view an optical element under a strong white light, properly coated optics will show a reddish-purple reflection. If the reflection from coated optics is yellow, green, or deep blue, the coating is of incorrect thickness, and light transmission through the instrument will be reduced. This is cause for rejection of the element.

A few scratches on the coating of an optical element will have no effect on light transmission; however, if most of the coating has been removed through improper cleaning or chemical action, the element should be replaced.

Reticles or other optics that are located at an image plane are never coated since scratches or other defects in the coating would be visible and very undesirable.

The mating surfaces of cemented lenses are not coated since there is no air-glass surface, therefore, surface reflection is not a problem. Reflecting surfaces of prisms are not coated for the same reason.

Inspect silvered prisms and mirrors for signs of wear, peeling, or darkening of the silvered or aluminized surfaces. All of these defects show up as blisters and cracks in the coating, or a yellowish color.

Some optical defects are illustrated in parts A through K in figure 7-2. If available, get some lenses with the defects shown, and study them as you read the following information.

CHIP.–A chip (fig. 7-2A) is a break at the edge of a lens or prism caused by uneven pressure or burrs on the seat of the lens mount.

NOTCH.–A notch (fig. 7-2B) is a ground off surface of a lens or prism. A notch is serious only if it is located where it will interfere with sealing or light transmission.

SCRATCH AND STRIPE.–A scratch (fig. 7-2C) remains visible as you rotate a lens or prism through 360°; a stripe, on the other hand, vanishes at some position as you rotate the optical element. You can see scratches and stripes most easily in optical elements when you place the elements against a dark background.

RING.–A ring (fig. 7-2D) is a circular mark around the external edges of a lens, and it is caused by wear of the lens by the mount seats and the retainer ring. An internal ring between the elements of the lens may appear at the edges of the lens when lens cleaning fluid dissolves the Canada balsam.

CRACK.–A crack (fig. 7-2E) is a fracture of the lens or prism generally caused by a sudden change of temperature, because the center of the optical element does not expand or contract as rapidly as its edge section.

BUBBLE.–A bubble (fig. 7-2F) may result from gases left in the glass during manufacture or from air which did not escape from the cement when the elements were joined.

STRIAE.–Striae (fig. 7-2G) look like veins or cords running through the glass, and you can see them by looking through the glass at a contrasting light and dark background. This is a manufacturing defect in the optical element.

BLISTER.–A blister (fig. 7-2H) is an air bubble trapped in the layer of cement between two lenses. If it extends toward the center of the lens, it is called a RUN-IN, generally produced by the dissolving action of a cleaning fluid. A blister, however, may result from uneven mounting during assembly of the instrument, or by dirt between cemented lenses. Blisters can be seen best by reflected light, and they usually increase in size over a period of time.

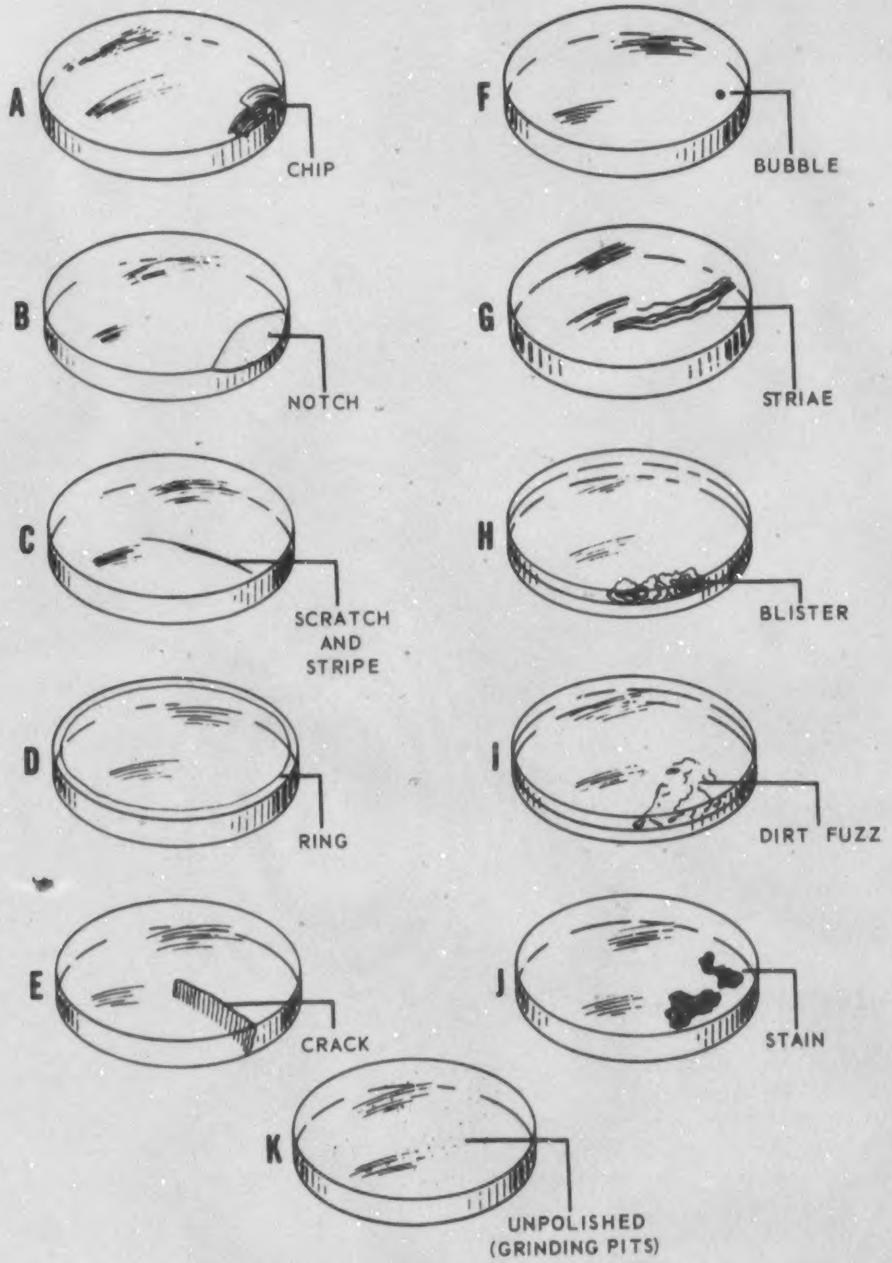
DIRT FUZZ.–Lint, dust, or dirt (fig. 7-2I) in the layer of a cement between lenses may eventually cause a blister. You can see this type of foreign matter in a lens most easily by transmitting light against a dark background. Dirt fuzz is caused by careless cleaning and cementing.

STAIN.–A stain (fig. 7-2J) is usually brown or green in color and is produced by evaporation of moisture which gets on lenses or prisms and dissolves some of the antireflecting coating, thereby causing a very faint deposit (sometimes bacterial in growth).

UNPOLISHED CONDITION.–An unpolished optic (fig. 7-2K) results from the manufacturer's failure to remove grinding pits from it. In some instances, however, this condition is apparent on optical surfaces exposed to gases, grit, and particles of all sorts in the atmosphere.

PARALLAX AND COLLIMATION.–The last step in checking the optical system of an instrument is to test for parallax and collimation of the instrument. Always check the collimation of an instrument before you disassemble it because the information you obtain will help you during repair and reassembly steps.

You can check the collimation of an optical instrument in two ways: (1) look through the instrument at an outside target, or (2) check it more accurately with an auxiliary telescope and



137.181

Figure 7-2.–Optical defects.

a collimator. The first method, however, is generally used when quick results are necessary.

Focus the instrument on a distant target and check for parallax by moving the eye from side to side and up and down. If parallax is present, the reticle (crossline) will appear slightly out of focus and seem to move back and forth or up and down over the target. If parallax is not present, the reticle will be in sharp focus with the target and remain superimposed in one spot on the target, regardless of the direction in which you move your eye behind the eyepiece.

DIOPTER SETTING.–To check the eyepiece diopter setting, focus the instrument on an infinity target and observe the position of the index mark on the diopter scale. If the index mark is not pointing to your personal diopter setting, 0 diopters is incorrect.

LEAN.–If the instrument has a porro prism erecting system, check the optical system for lean by looking through the instrument with one eye at a vertical target (flag pole or side of building) and by looking directly at the target with the other eye. If the two images are not PERFECTLY parallel, there is lean in the optical system; that is, the image through the instrument appears to lean in relation to the image observed with the naked eye. The reason for this lean is that the porro prisms are not mounted at 90° to each other.

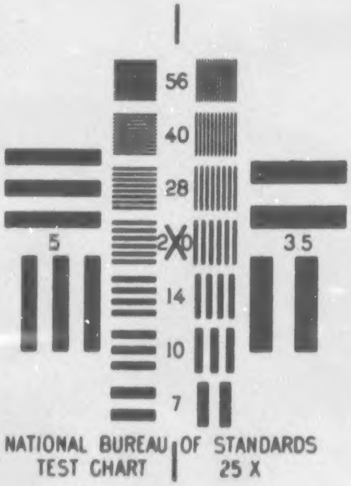
TESTING OF INSTRUMENTS

As you know, good performance of an optical instrument is obtained only when the images it creates are free of aberrations. Optical performance is basically a function of design of the instrument and cannot be varied unless the characteristics of the optical elements are changed. There are several possible service defects, however, which can change the optical qualities of one or more elements. An optical element under strain by mechanical parts, for example, or tilted and improperly positioned elements (faulty mounting), badly matched recemented optics, and even incorrect optics all cause poor image infidelity.

Image Fidelity

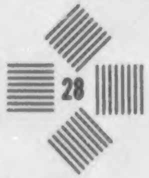
The accuracy of reproduction in an image and the absolute clarity of an image are termed image fidelity. When you check the image fidelity of an optical instrument, check for two things: CENTRAL RESOLUTION and CENTRAL ASTIGMATISM.

Take a close look at figure 7-3, which shows a standard test chart for testing image fidelity in optical instruments, and figure 7-4, which is the test pattern for astigmatism. These test charts are available through naval supply channels.



137.182

Figure 7-3.–Image fidelity test chart.



137.566

Figure 7-4.–Astigmatism pattern.

Image fidelity test chart values (fig. 7-5) list the space between the centers of adjacent lines as lines per inch, the distance from which you should view the chart, and the resolution requirements in terms of angle in the field for each class of instrument. The corresponding pattern for the astigmatism test is also given in terms of the number of lines per inch. These are selected for convenient viewing at the same distance prescribed for the resolution test.

The angular limit of resolution is related inversely to the diameter of the objective lens, which means that it is advisable to have large objectives for sharp definition. A target shooter would choose a scope with a 1 1/4-inch objective (diameter), or even larger. A pair of 7 X 50 binoculars provides good resolution because of the large size of the objective (50 mm in diameter), and for this reason, it is better than a pair of 7 X 35 binoculars, with a 35 mm objective.

To test the image fidelity of any particular instrument, select the proper pattern from the chart (fig. 7-5), locate the pattern at the distance specified, and focus the instrument on the pattern. If you do not get a clear, undistorted image of the test pattern, image fidelity is poor.

Although the resolving power of the human eye is equal to 1 minute of arc, it is reduced to 2 or 3 minutes of arc by eye fatigue after continuous observation. For continuous operation, therefore, you need an instrument of greater power to get the same definition you would get with a lower-power telescope used for short intervals.

PROCEDURE FOR TESTING AN OPTICAL INSTRUMENT FOR ASTIGMATISM:

1. Use the proper test chart and set it at the distance given in the listing of values. Sight the test pattern with the instrument to be tested, and line up the center of the astigmatism pattern in the center of the field of view.

2. Place an auxiliary telescope to the eyepiece of the instrument undergoing the test and adjust it to bring the horizontal set of lines into sharp focus. Note the diopter reading on the auxiliary telescope. CAUTION: The focusing adjustment of the primary instrument (one undergoing the test) must NOT BE CHANGED after you perform the preceding operation.

Instrument	Θ Resolution Min. Limit in Seconds of Arc	Resolution $\frac{1}{S}$ Lines per inch	D in feet	Astigmatism $\frac{1}{S}$ Lines per inch
7 x 50 Binocular	4	56	77	28
Telescopic Alidade	11	40	39	20
Ship Telescope	4	56	77	28
Azimuth Telescope	8	40	54	20
Sextant Telescope	18	40	24	20

137.183

Figure 7-5.—Image fidelity test chart values.

3. Check the vertical set of lines for focus. If it is not sharp, astigmatism is present. To put the vertical set of lines in sharp focus, adjust the auxiliary telescope diopter ring. Observe the diopter reading.

4. The maximum allowable difference between the horizontal and vertical lines is 0.15 diopters for the primary instrument being tested. Divide the diopter difference found in the auxiliary telescope, steps 2 and 3, by the square of its power to arrive at the corresponding change that would be found in the primary instrument without the auxiliary telescope. For example, the diopter change in the primary instrument equals:

$$\frac{\text{Diopter Change in Auxiliary Telescope (DCA)}}{(\text{Power of Auxiliary Telescope}^2)}$$

As you can see, the auxiliary telescope increases the sensitivity of the test by the square of its power. The maximum allowable diopter difference for typical auxiliary telescopes is as follows:

Power of Auxiliary Telescope	Maximum Allowable Diopter Difference
3	1.35
4	2.40
5	3.75
6	5.40

5. If the horizontal and vertical lines are in focus within the allowable tolerance, repeat steps 2 and 3 for the diagonal sets of lines. The same tolerance prevails.

NOTE: Excessive astigmatism may be caused by a defective or poorly mounted lens. Check the objective lens first and then the reflecting surfaces of the prisms (objective prism first). These surfaces must be optically flat to close tolerances.

Poor resolution is caused by defective objective lenses and prisms. Always replace the objective lens first. Misplaced, unmatched, and shifted prisms cause trouble because they displace the line of sight. A bad reflecting face on a prism also causes poor resolution.

To check an optical instrument for flares and ghosts, point it toward a small, bright object against a dark background and focus sharply. If you observe rings or streaks of light, or one or more faint ghost images, the instrument has excessive internal reflection. These defects indicate that the optics need recoating or that the interior of the instrument needs a nonreflecting coating.

Illumination and Contrast

Reproduction of an image depends upon the amount of light received by the objective and the effective transmission of this light through the instrument. For maximum efficiency at any given light intensity, the exit pupil of an optical instrument must equal the entrance pupil of the eye under the same conditions. Opaque foreign substances—dust, oil, or lint, for example—on any optical surface reduce illumination in the system and adversely affect the contrast between light and dark shaded areas of the target.

To test for illumination and contrast in an optical instrument, focus the instrument on a distant object and check the clarity of the image. The image should be nearly as bright and well defined as the object appears to the naked eye. If the image is dim or indefinite, look for dirty, stained, or uncoated optical surfaces, darkened mirrors or cement, or damp or oily optics.

Spherical Aberration

To test an optical instrument for spherical aberration, cover the outer half of the objective with a ring of black paper, focus sharply on a distant object, and read the diopter scale. Then remove the ring of paper and cover the inner half of the objective with a black disk. Refocus the instrument and read the diopter scale again.

If the amount of movement of the eyepiece for focusing is very small, the instrument is well corrected for spherical aberration.

Chromatic Aberration

To test an optical instrument for chromatic aberration:

1. Set up a white disk against a black background, far enough away so that you can focus the instrument sharply. When the image is in focus, it should have no color fringes.

2. Focus in a short distance and look for a light-yellow fringe around the image of the disk.

3. Refocus and then focus out a short distance, at which point the image should be fringed with pale purple.

The two fringes around the image (light-yellow and pale-purple) constitute the SECONDARY SPECTRUM of the optical system, and they show that the system is well corrected for primary chromatic aberration (red and blue).

Coma

Focus the instrument sharply on a small, round, white object near the edge of the field and study the image produced. If the image is circular and flareless, the instrument is free of coma.

NOTE: Test for coma at five or six different points around the outer edge of the field.

Distortion

To test an optical instrument for distortion:

1. Rule a pattern of vertical and horizontal lines on a large sheet of cardboard and put it where the pattern nearly fills the field of view of the instrument.

2. Focus the instrument sharply and check the image, which should be composed entirely of straight lines. If any of the lines appear curved, the image is distorted.

OVERHAUL AND REPAIR

As an Opticalman, you have a complicated job. To repair and overhaul optical instruments, you will use a wide variety of tools; you will need special skills and a lot of information on many subjects. Only by careful practice can you develop skill in using your hands. You will never do it just by reading a book. The best we can do in this chapter is to try to get you started right.

We will give you a brief introduction to subjects like these: the use of handtools; soldering and silver brazing; handling chemicals; the use of blueprints; heat treating metals; cleaning and painting optical instruments; and cleaning and cementing optics. We will introduce you to your tools, tell you what they are for, and give you a few tips that will save you time and trouble. The rest is up to you. Stay alert, look around you, and ask questions. Learn all you can about each job. Then, when you understand it, try it for yourself.

Keep your working space, your clothes, your tools, and your hands strictly clean. It is a good idea to cover the top of your workbench with a large sheet of clean, light-colored paper before you begin to work. You can keep your hands from sweating by washing them frequently in cool water. Any fingerprints you leave on an optical element will etch the surface and destroy the optic.

The old saying "a place for everything and everything in its place" is especially true in the optical shop. You cannot do an efficient repair job if you have to stop and look around for every tool you need. Keep each tool in its place, whether it is in your toolbox or the shop toolroom. When you have finished with it, do not put it back until you have cleaned it. You will do better work, with less effort, if you keep your tools in good shape and use them only for the jobs they are intended to do.

COMMON TOOLS

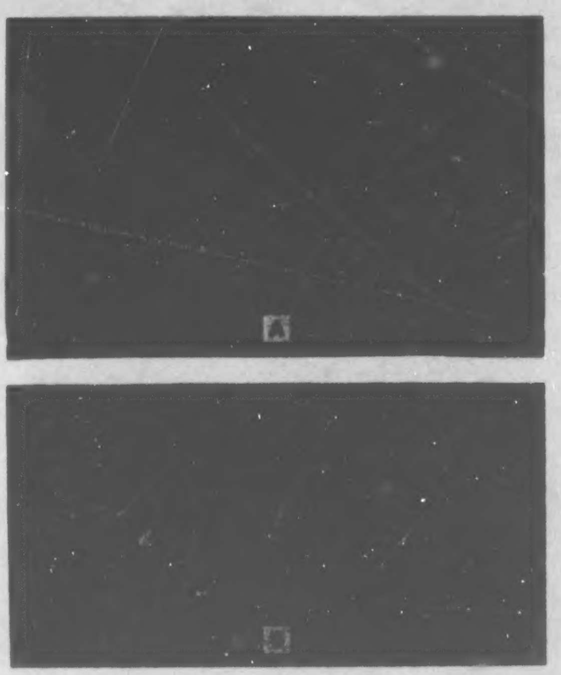
Many of the tools used in optical repair work are common handtools which are thoroughly discussed in *Basic Handtools*, NAVEDTRA 10085 Series. However, the quality of the tools and their condition are vital to the work done on precision optical instruments. When you select a tool for use in the optical shop, be certain that it is the highest quality tool available and that it is in good condition. Your skill in selecting, maintaining, and handling tools is a measure of your expertise in the OM rating.

SPECIAL TOOLS

Of all the various tools used by an Opticalman the most vital are special tools which are used specifically for optical work. These special tools may be manufactured by the repairman himself, or on rare occasions, purchased through normal supply channels. When you must manufacture a special tool, the same quality standards that apply to all optical instruments must be used to ensure that the tool is properly made.

The first step in manufacturing a tool is to make a sketch which shows exact dimensions and the type of material that is to be used. If you are in doubt about the procedure to follow or which machinery to use in making the tool go the shop supervisor for guidance. Remember: NEVER operate any machinery until you are thoroughly familiar with the operating instructions and safety precautions.

Some of the special tools used constantly in optical repair work are discussed in the following paragraphs.



137.185

Figure 7-6.—Retaining ring wrenches.

Pin Wrenches

Study the different types of wrenches shown in part A of figure 7-6. These wrenches are known as adjustable spanner or pin wrenches and are manufactured by the repairman. Part B of figure 7-6 shows an Opticalman using the blade portion of a pin wrench to rotate a slotted retainer ring in a lens mount. A retainer ring may be made with two small holes (instead of slots) spaced 180° apart, in which case the pointed tips of the wrench are used to turn the ring. This special tool is adjustable, and it can be used to remove or tighten retaining rings of various sizes.

CAUTION: Slippage of a pin wrench during use can damage unprotected optical surfaces, as well as the retainer ring and mount. To prevent any damage, be very careful when you use the wrench; be sure it fits properly in the slots or holes of the retainer ring, and protect optical surfaces with rubber, blotting paper, or clean cardboard disks.

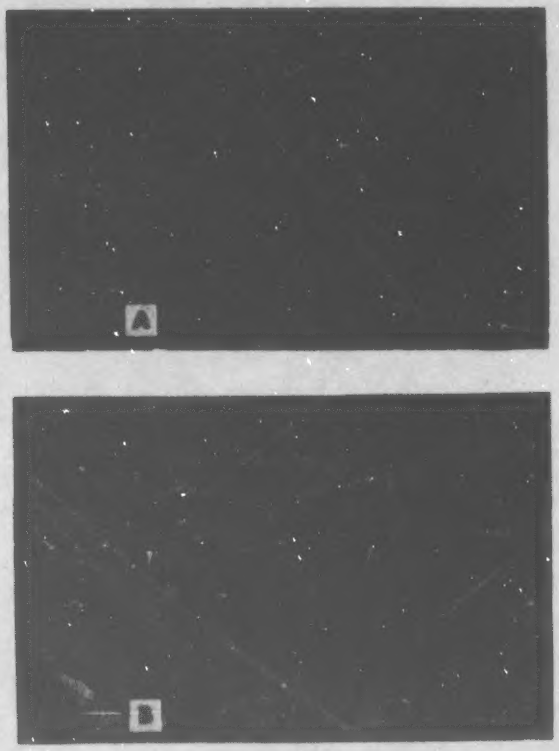
Grip Wrenches

Figure 7-7 shows a grip wrench (part A) and the procedure for using it (part B). A grip wrench is made of fiber with holes in steps of 1/16 inch, ranging in size from 1/2 inch to about 1 inch, and then at 1/8 inch intervals up to sizes of about 4 inches.

When you use a grip wrench, select the smallest size, which meets a specific need, without forcing it onto the part you must turn. CAUTION: Grip wrenches can exert tremendous pressure. Most optical parts are, by necessity, thin and light. To prevent crushing the parts, try to use the grip wrench over the portion of a tube reinforced with a retainer ring or lens mount.

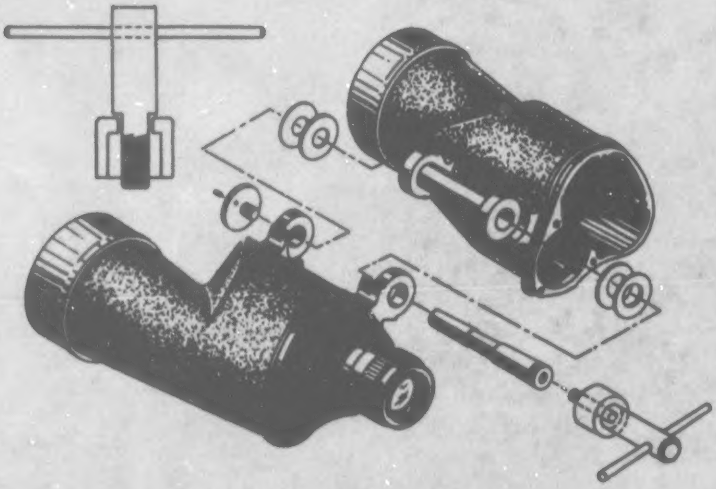
Hinge Pin Puller

Some special tools are useful for only one purpose and are used on only one type of instrument. A binocular hinge pin puller is an example of such a tool. Figure 7-8 shows a cross section of a hinge pin puller with which you can pull and install a tapered binocular hinge pin without damaging other components of the hinge.



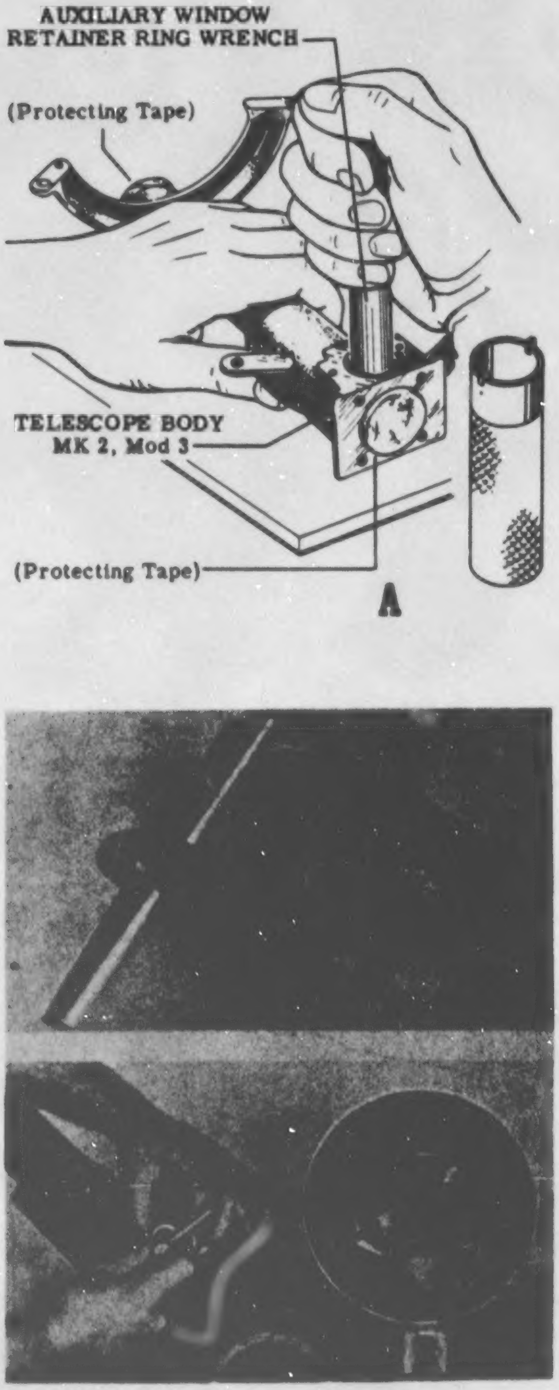
137.184

Figure 7-7.—Grip wrench and procedure.



137.187

Figure 7-8.—Binocular hinge pin puller.


AUXILIARY WINDOW RETAINER RING WRENCH
(Protecting Tape)
TELESCOPE BODY MK 2, Mod 3
(Protecting Tape)
A

137.187

Figure 7-9.—Special retainer ring wrenches.

Special Retainer Wrenches

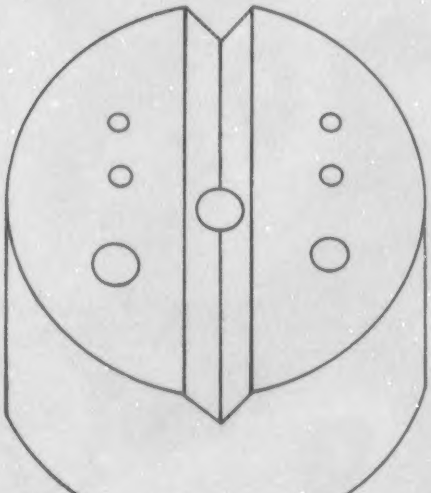
Take a look now at part A of figure 7-9 which shows a special wrench used to remove or tighten a retainer ring. Part B shows another type of retainer ring wrench which you will use occasionally for making and holding an adjustment with the center wrench, while tightening the lock ring with the outer wrench.

Bench Block

Figure 7-10 shows a bench block. It is used to support mechanical parts for center punching and for driving out taper pins or similar retainers. You will manufacture this particular design yourself, or you can make a bench block of any style to suit your purposes.

Thread Chaser

The thread chaser is an indispensable tool used for removing dirt, corrosion, and burrs from threaded parts. There are two basic types



137.525

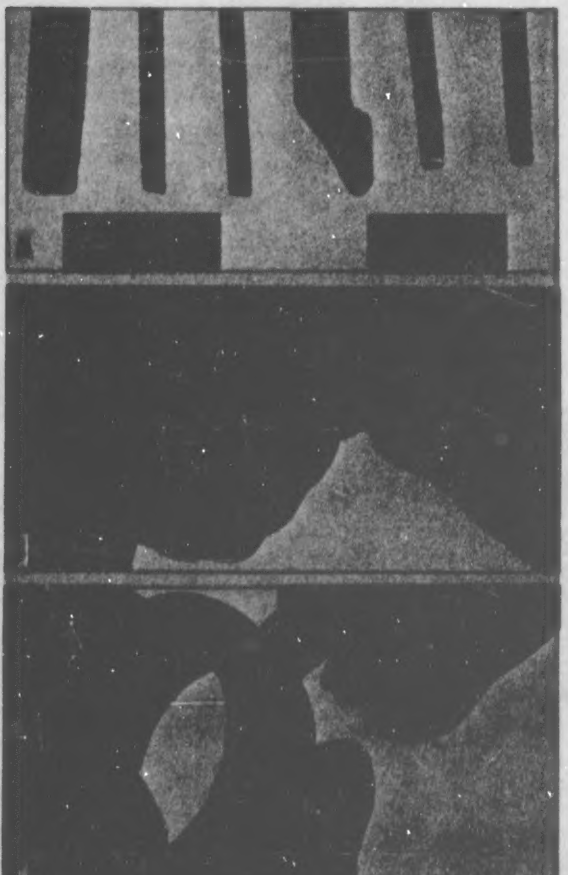
Figure 7-10.—Bench block.

(fig. 7-11)—one for inside threads and the other for outside threads. Be sure to use the right type, and carefully check the thread size before you use them.

Since optical instruments are manufactured with many nonstandard thread sizes, you cannot use taps and dies on many components to restore threads. For this reason, thread chaser sets are available in sizes from 3 threads per inch to 80 threads per inch.

Geneva Lens Measure

A Geneva lens measure (fig. 7-12) is an instrument for measuring the dioptric strength of thin lenses by indicating the amount of curvature on their surfaces. The outside red scale is graduated to read clockwise in quarters of a diopter from 0 to -17 diopters; the inner black scale is graduated to read counterclockwise in quarters of a diopter from 0 to +17 diopters.



137.526

Figure 7-11.—(A) Types of thread chasers. (B) Reshaping inside threads. (C) Reshaping outside threads.

137.186

Figure 7-12.—Geneva lens measure.

The index of refraction of the glass for which a Geneva lens measure is designed is printed on the dial (1.53); this number is the index of refraction of crown glass. A formula, however, permits you to use the gage to measure types of glass with different indices of refraction.

To use a Geneva lens measure, place the contact points directly on the polished surface of the lens. To ensure accurate readings, hold the gage perpendicular to the surface of the lens and in the center. The outer points (2) of the gage are stationary, and the center point activates the dial pointer. If the pointer indicates zero, the surface of the lens is PLANO. Readings for convex surfaces will be PLUS; readings for concave surfaces will be MINUS.

Take the reading in diopters of one lens surface and then measure the other surface. When you add the dioptric strength of each lens surface, you get the total dioptric strength of the lens, if its index of refraction is 1.53.

When you must take a reading of a lens with an index of refraction other than 1.53, use the following formula: (n = index of refraction of lens)

$$\text{True DP of Lens Surface} = \frac{n - 1}{0.53} \times \text{reading of lens surface with the gage}$$

To use this formula, take a reading of the first lens surface and transpose its dioptric strength into the formula to get the true dioptric strength of the first surface. Then, take a reading of the second lens surface, put your results in the formula, and solve it for the true dioptric strength of the second surface. The sum of the two answers you got by solving the formula is the total dioptric strength of the lens.

Remember that the dioptric strengths of the two lenses have opposite signs; that is, the positive lens has a positive dioptric value and the negative lens has a negative dioptric value. You must account for this when you add the two values.

Because a compound lens is constructed of a positive and a negative lens of different indices, you cannot use a Geneva lens measure to obtain its dioptric strength. But if the two elements of the lens are separated, you can get the dioptric strength of the individual elements and add both results to get the dioptric strength of the combinations.

Since a Geneva lens measure is designed to measure the curvature of a lens' surfaces, use a Geneva lens measure to make certain that the positive lens surface matches the negative lens surface when cementing compound lenses.

DISASSEMBLY

Before you do any repair work on optical instruments, clean your work space and get everything ready and in position. Clean the outside metal and painted surfaces with a clean, soft cloth (used for this purpose only). If a solvent is required to remove grease or foreign matter, use only an approved cleaning agent.

If your casualty analysis indicates that the instrument must be partially or completely disassembled to effect necessary repairs, follow the procedure discussed next.

Procedure

If you do not fully understand an instrument you must overhaul, get a disassembly sheet and follow it or follow the disassembly procedure in the applicable naval publication (NavShips manual; Ordnance Pamphlet). These authentic sources provide information on troublesome areas pertaining to disassembly, and they also list the precautions you should take.

CAUTION: Before you disassemble any optical instrument, determine whether it is a pressure-tight type. If it is gas filled, release the gas pressure slowly by opening the gas outlet valve. NEVER begin disassembly until the pressure is fully released.

In the interest of production, experienced optical repairmen work on more than one instrument at a time, especially when all the instruments require a major overhaul. If you must work on more than one instrument at a particular time, keep the parts of each instrument in separate containers, and label the parts for easy identification. One of the surest and best ways to label parts is to scribe each metal part with an identifying mark.

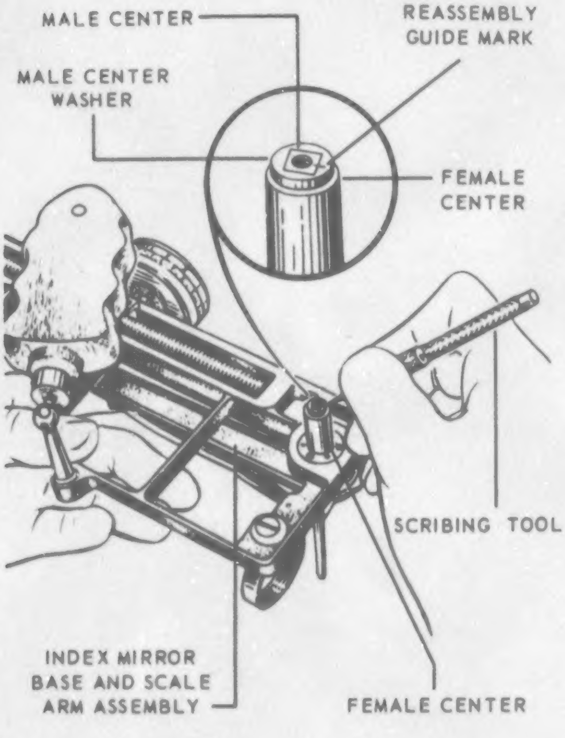
When you are giving four pairs of binoculars a general overhaul, for example, you can label the parts of the first binocular #1, the parts of the second binocular #2, and so on. To satisfactorily identify the parts for right and left barrels, add an R (right) or an L (left), as appropriate. Your markings on the parts for the right and left barrels, would then be #1R, or #3L, and so forth. Be careful to scribe these marks where they will not be covered with paint later and where they will not affect the performance of the instrument.

Other markings which you may be required to make or check during disassembly are ASSEMBLY MARKS. When a manufacturer makes an optical instrument, he fits certain parts by hand and, if there is danger of incorrect assembly of these parts during a later overhaul, he marks them with a small punch mark or a scribe line (on each part of an assembly). When you disassemble an optical instrument, therefore, look for these assembly marks; if they are missing, make appropriate marks of your own. Figure 7-13 shows the procedure for marking a part.

Optical elements (glass) require another marking technique, which must meet two requirements: (1) the direction the optic must face when reassembled, and (2) the function the optic serves in the optical system.

You can identify the function of the optic by writing on the frosted portion the following: Obj. (objective lens), #1 Er. (first erector), #2 Er. (second erector), and so on until you mark the last element in the system. The first erector receives the light from the objective and should therefore be numbered first. Use a soft-lead pencil or an instant-drying marking pen.

The accepted method for determining the direction an optical element must face in a system is to mark an arrow on the frosted edge of a lens or prism, the tip of which indicates the direction of light through the instrument.



137.188

Figure 7-13.—Scribing an assembly mark.

If you presume a lens in a system is facing the wrong direction, study the diagram for that particular instrument (MARK and MOD) as you remove the lens. You can also use a Geneva lens measure to check the curvatures of the lens against those listed on the optical diagram.

Start your disassembly of an optical instrument by removing exterior parts which hinder further disassembly or by removing an exterior retainer ring, cover cap, or access plate (secured by screws). These exterior parts may occasionally be frozen because they have been exposed to the weather. That is, metal parts in close contact become stuck together as a result of corrosion, electrolytic action, or natural affinity for each other. Aluminum-to-aluminum joints have the greatest tendency to freeze (also called seize). Salt-laden atmosphere enhances the tendency of metal parts of navigational instruments to seize together. If the moisture seal of the instrument is faulty, salt-laden moisture will most likely cause seizing inside the instrument.

Frozen Parts

To remove frozen parts:

1. Apply penetrating oil or, when time permits, soak frozen joints in penetrating oil.
2. To prevent damage to parts which come off easily (especially optics), remove them first.
3. Use proper tools, and do not crush parts with wrenches.
4. If you cannot remove a lens, cover it with a pad of blotting paper, or a rubber disk of the same size.
5. Use shaped wooden blocks to hold a part in a vise. Powdered rosin on the blocks helps to hold a part and prevent it from slipping out of position. Then use a pin wrench or grip wrench of the proper size to attempt to remove the frozen part.
6. If a joint is still frozen after you have soaked it a reasonable time in penetrating oil, proceed as follows:

    a. Remove the part from the vise and tap the joint sharply with a rawhide mallet while turning the part.

b. Tap all around the joint several times with the mallet. The sharp blows, combined with the penetrating oil, will often free the joint.

c. Replace the part in the shaped blocks in the vise, then use the proper wrench to separate the parts.

d. If the parts do not break free after you use the rawhide mallet, apply heat to the joint. Do not use so much heat that you burn the paint; you merely want to expand the outer portion of the joint. Now try the wrench again.

e. If the parts are still frozen, apply more penetrating oil to the hot joint. You may need to use impact to try to separate the parts. Hold your wrench firmly and strike the wrench sharply with a mallet. Several sharp blows will usually free a stubborn retainer.

CAUTION: Use extreme care and patience when you apply heat and pressure to frozen joints, lest you cause distortion (twisting and bending) of metal parts and breakage of optical elements you could not remove at the outset.

7. If frozen parts do not yield to the procedures just outlined, salvage the most expensive part or parts by carefully cutting, breaking, or machining away the other frozen part or parts. When a retainer ring is frozen, for example, drill a hole down through it towards the lens; but use care, do NOT drill too deeply and ruin the lens with the drill. The diameter of your drill should be slightly less than the thickness of the ring.

After you weaken the ring by drilling the hole, carefully bend the ring out at that point and remove the free ring and lens.

NOTE: Some retainer rings are kept in place (made vibration proof) by an application of shellac or a similar substance on the threads of the mount and the edge of the ring. You can soften this compound by repeated applications of lacquer thinner or alcohol.

8. To remove screws and setscrews with stripped slots or heads twisted off, proceed as follows:

a. If a screw if frozen in a hole as a result of corrosion, loosen it with penetrating oil and heat. NOTE: Do this before you try to remove the screw by any other means.

b. If the body of a screw protrudes above the surface of a part, file in a new screwdriver slot with a small swiss slotting file and remove the screw with a screwdriver of proper size. You can often remove some protruding screws with parallel motion pliers.

c. If a screw is deep in a tapped hole, use a sharp scribe tip and, if possible, make a new slot in the screw. This process is slow and requires patience and care.

d. If the procedures just described do not work, use one of the following procedures to drill the screw out:

(1) For very small screws, use a drill slightly smaller in diameter than the minor diameter of the screw and drill through the screw. The outer shell and threads of the screw will remain, and you can run a tap of correct size through the hole to finish the job.

(2) On screws of larger size, drill a hole of proper size in the screw and remove it with a screw extractor. (Each extractor has a drill of recommended size to use with it.)

REMEMBER THAT PATIENCE AND CAREFUL, INTELLIGENT WORKMANSHIP ARE REQUIRED TO REMOVE FROZEN PARTS FROM AN OPTICAL INSTRUMENT, but do not spend more time on an instrument than it is worth. Consult your shop supervisor whenever you are in doubt.

After you remove all frozen parts, continue with the disassembly. Remember to mark all optical and mechanical parts. Before you turn off a retainer ring or try to unscrew or slide a lens mount, remove the setscrews which secure them. Some of these screws may be hidden under sealing compound, so check for them carefully. Failure to remove these setscrews may ruin a part.

Be extremely careful when you remove optical elements and gear assemblies through openings in the optical chamber. These parts can be easily damaged by striking other parts or the chamber housing. When you remove a part which exposes the interior of the optical chamber of an instrument, make sure you tape the opening or close it in some manner to keep out foreign matter.

As you remove parts and assemblies from the interior of an instrument, check them for damage not previously noted, and write your findings on the casualty analysis sheet for future reference.

Thus far, with few exceptions, our discussion of disassembly of an optical instrument has covered mostly mechanical parts because this is the proper sequence for disassembling the instrument. As you disassemble an instrument, remove each lens mount and cell and set it aside for further disassembly after you complete the major disassembly of mechanical components.

Lenses from Mounts

The techniques we will discuss for removing lenses from mounts are primarily for lenses mounted with a sealing compound, but they are also applicable to the removal of optics difficult to disassemble. The procedures to follow (and precautions to use) when you disassemble optical elements from their mounts cannot be formulated as step-by-step instructions. The information which you should keep in mind when doing this work may be classified as follows:

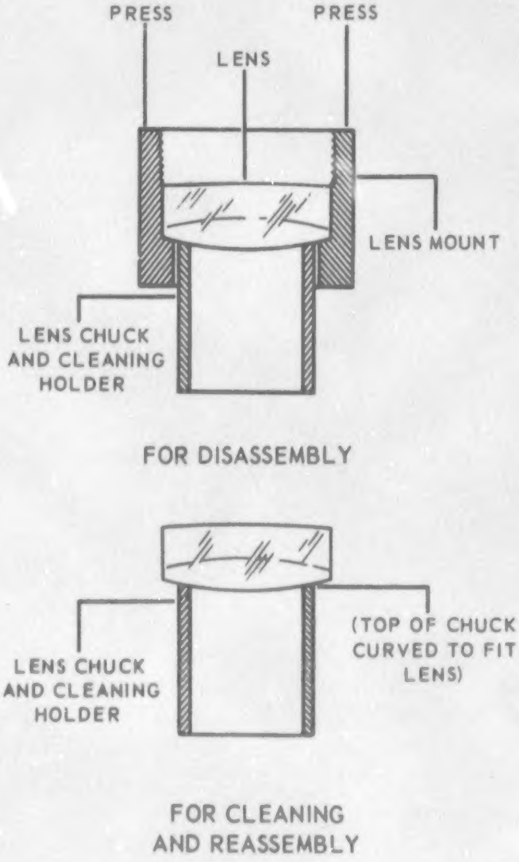
1. Although optical glass is easily chipped or cracked and easily damaged by shock, steady pressure within limits does not ordinarily crack a lens if the thickness of the glass is sufficient.

NOTE: Removal of the eyepiece and the objective lens is usually more difficult than removal of other optics, because these two lenses are usually sealed in their mounts with a sealing compound or gasket. Also, these lenses are often doublets, which means that excessive or uneven pressure on the lenses can cause damage to the cement used to put them together, or cause the thin planoconcave flint element of the eyepiece to break.

2. Shearing action caused by uneven pressure is the greatest enemy of cement between optical elements; therefore, to force a compound lens out of its mount, press down squarely and evenly over a large part of its area. A device similar to that in figure 7-14 may be used to support the lens. Note the name of this device, LENS CHUCK AND CLEANING HOLDER. It is a cylindrical brass tube with the edges at one end beveled to match the curvature of the lens. By exerting even pressure on the lens mount, you can break the seal. Observe that the word PRESS in the illustration indicates the points where you should apply pressure.

3. An application of heat to a lens mount helps to loosen it from the lens in two ways:

   a. The metal expands more than the lens.


PRESS
PRESS
LENS
LENS MOUNT
LENS CHUCK AND CLEANING HOLDER
FOR DISASSEMBLY
LENS CHUCK AND CLEANING HOLDER
(TOP OF CHUCK CURVED TO FIT LENS)
FOR CLEANING AND REASSEMBLY

137.189

Figure 7-14.—Lens chuck and cleaning holder.

b. Most sealing compounds are softened by moderate temperature.

CAUTION: A temperature of 125° to 140°F softens Canada balsam used to cement the elements of compound lenses together. If a compound lens does not yield to pressure and an application of heat at low temperature, the Canada balsam probably melted previously and ran out between the elements of the lens and the mount and hardened a second time. When this happens, a temperature of about 300°F is required to soften the cement.

4. When you remove a lens from its mount, protect its surfaces with a clean cloth or tissue paper. DO NOT TOUCH POLISHED GLASS OPTICAL SURFACES WITH YOUR FINGERS. Be sure to mark the path of light through the lens to ensure that you reassemble it correctly; then wrap the lens in lens tissue (several thicknesses) and place it where the mechanical parts cannot damage it.

5. When you cannot push a lens out from the back, as is sometimes the case, use a small suction cup or piece of masking tape to grip the lens and then ease it out of the mount.

CAUTION: Large thin lenses have a tendency to twist diagonally (cock) as you try to remove them, so use care to prevent cocking. To loosen a cocked lens, tap lightly on the edge of the mount on the side where the lens is stuck. As you tap the mount, hold it so that the lens will eventually drop out into your hand. If you accidentally touch the lens with your fingers, clean it thoroughly at once to remove salts and acids deposited by your fingers.

REPAIR PROCEDURE

When you start to overhaul and repair an optical instrument, refer to the notations you made on the casualty analysis sheet prior to and during disassembly. Use this information as you proceed with the repair process.

Cleaning and Inspecting Parts

The first phase of overhaul of the instrument is cleaning the mechanical parts. Cleaning solvents, which may be slightly toxic and irritating to your skin, must be used in well ventilated spaces only. Avoid prolonged contact of your hands with the solvent. The best policy (safest) is to use solvents only in a space specified for their use.

A cleaning machine of the type shown in figure 7-15 is excellent for cleaning small mechanical parts of optical instruments. An electric motor on the machine revolves a basket of parts in two cleaning solutions and a rinse solution. The machine also dries the parts by blowing hot air through the basket.

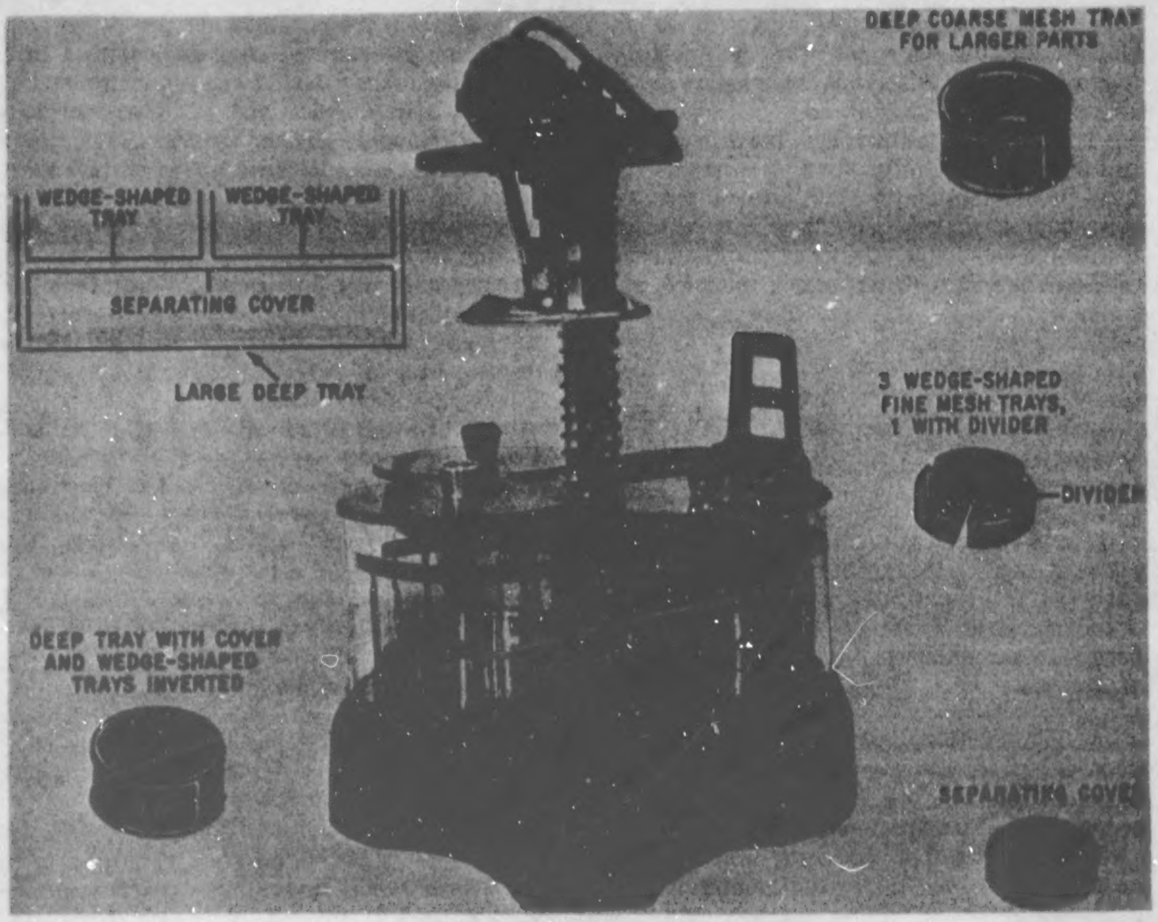
Another type of instrument cleaning machine consists of a tank of solvent agitated by low-pressure air. The newest types of cleaning machines use ultrasonic sound to act on an approved liquid cleaning agent to degrease and clean the parts.

NOTE: When you use a cleaning machine, follow the instructions listed in the manufacturer's technical manual. If you do not have this manual, consult your shop supervisor.

If your shop does not have a cleaning machine, use a stiff-bristle brush to clean instrument parts in a container of cleaning solvent. This is one of the best methods for cleaning large or very dirty parts. Solvents leave an oily residue on clean parts, and you must remove it by rinsing the parts in an approved degreasing agent, or by scrubbing the parts in hot soapy water. (Traces of oil on the interior of an optical instrument may later get on the lenses and affect image fidelity.)

After you clean instrument parts, inspect them for traces of lubricants, grease, sealing compound, or dirt. Scrape off dirt and grease not removed during the cleaning process.

CAUTION: Do NOT scrape bearing surfaces. As you examine each cleaned part, look for defects previously hidden by dirt, wax, or grease. Also check them for corrosion. Replace badly corroded parts.



61.101

Figure 7-15.–Instrument cleaning machine.

Place the cleaned parts in a suitably clean container and cover the container to protect the parts from dust and dirt.

Repair Categories

Now that you have cleaned and inspected the parts of the instrument undergoing repair, proceed immediately with the repairs. The repair process generally consists of three methods: (1) repair and refitting of old parts, (2) using a new part (replacement) from stock, and (3) manufacturing and refitting a new part. Each of these categories is discussed in some detail in the following sections.

REPAIRING OLD PARTS.–Repair reusable old parts, as necessary, and refit them into the instruments from which you removed them.

If a part must be straightened or re-formed to its original shape, strike it carefully with a soft-faced hammer. CAUTION: Give the part necessary support before you strike it to avoid further damage.

When you discover stripped or damaged threads in a tapped hole, drill the hole out whenever possible and retap it for a screw of larger size; but do not go over two screw sizes larger than the original size stated on the blueprint. If the screw size must be exactly as stated on the blueprint, proceed as follows:

1. On steel, bronze, and brass parts, drill and tap the hole two or three screw sizes larger than original; plug the hole with a screw of corresponding metal. Use silver solder to secure the plug; then file the plug flush with the surface of the part, and drill and retap a hole of correct size.

2. Repair aluminum parts with stripped threads in the same manner as you repair parts made of other metals. It is difficult to solder aluminum parts, however, and it is best to ask the shop supervisor to have the soldering done in another facility, if possible. When the soldered part is returned to you, dress the soldered area, and redrill and tap the hole to the size specified on the blueprint.

3. Dress up scratched, burred, and dented parts, in accordance with prescribed shop procedures.

Be careful when you repair parts to prevent damage to precision bearing surfaces machined on them. Use a stone or a bearing scraper to remove burrs from a bearing surface, and be careful to remove only the burr. Do NOT file a bearing surface, for filing may completely ruin it.

When you complete repairs on an instrument part, refit the part on the instrument and check its action and/or operation for accuracy. If necessary, scrape off a slight amount of a surface to make a part fit properly. Redrill undersized holes and make other necessary changes to your repair job to make the part fit correctly. After you fit a part, DO NOT FORGET to make an assembly mark on it to indicate direction of installation.

CAUTION: Reassembly of an instrument containing improperly fitted parts may require later disassembly of part or all of the instrument.

REPLACE PARTS.–Sometimes a part is damaged to such an extent that it must be replaced with a new part. One source of replenishment is from stock.

When you receive a replacement part from stock, try it for proper fit in the instrument or assembly. If it does not fit, take necessary action, including machining. A manufacturer, for example, does not drill dowel pin and screw holes, so you must drill them to correct size wherever required. A manufacturer also makes bearing parts slightly oversized, so that you can fit them properly by hand. Do not forget to make assembly marks on the new parts after you fit them, to ensure correct fitting into the instrument later.

MANUFACTURED PARTS.–Occasionally, your shop supervisor can have parts made by submitting an intershop job order. There will also be times when you will be required to manufacture parts. The procedure for doing this is as follows:

1. Use information on the old part, or its name, to locate the blueprint. Follow blueprint dimensions to manufacture the part.
2. If a blueprint cannot be located, use the old part as a sample to obtain dimensions.

Miscellaneous Repairs

When you give an instrument a predisassembly inspection, you may note undamaged moving parts in the instrument which are dry, tight, grinding, or rough in action. You will find in some instances a combination of these malfunctions, and even others not mentioned here.

When you make miscellaneous repairs to an instrument, look for all types of troubles and remedy them, including lack of or dirty lubrication, excessive or insufficient clearances, incorrect alignment, and improper assembly. If the cause of malfunctioning is not readily apparent, proceed as follows:

1. Clean all mating parts.
2. Make a trial assembly, but do not force parts.
3. Check for proper clearance to determine the cause of binding or excessive lost motion.

When cleaning, lubrication, and proper alignment of parts fail to correct casualties and/or malfunctioning, take the action discussed in the following paragraphs.

INSUFFICIENT CLEARANCE.–If there is an insufficient amount of clearance on such parts as tapered sleeve bearings, ball and socket bearings, and multiple-lead thread eyepieces, do this:

1. Make a thin solution of pumice and clock oil (small amount of pumice at first) and put a little of the solution on the parts as you reassemble the bearing.
2. Work the parts back and forth, or rotate them, until their movement is of desired freedom.
3. Disassemble the parts and wash out all traces of pumice and oil.
4. Reassemble and lubricate with the proper type of lubricant, and check the motion.

Follow the procedure just described until you obtain the desired fit.

When there is insufficient clearance on a flat, sliding-surface bearing, do the following:

1. Put a thin coat of prussian blue (machinist's dye) on a surface plate and rub the oversized portion of the bearing assembly over the prussian blue.
2. Carefully scrape away the high spots on the bearing indicated by the prussian blue.

CAUTION: Remove only a small amount of metal at a time, and make a trial assembly after you remove each amount. The important thing is to prevent the removal of too much metal from the bearing.

Another method for removing excess metal from a sliding-surface bearing is to spread a small portion of a thin mixture of pumice and clock oil over the surface of a flat lap and rub the high part of the bearing over the surface of the coated flat lap. Use a sweeping figure-eight motion to ensure uniform removal of the metal. Do NOT remove too much metal.

EXCESSIVE CLEARANCE.–If there is no way to adjust the desired fit by removing excessive clearance with shims or if the bearing does not have some means by which it can be adjusted, replace it with a new one. If there is some way to adjust the bearing, however, adjust it as necessary to get a tight fit and then remove high spots in the manner described for obtaining sufficient clearance.

NOTE: Always mark bearing parts to ensure proper assembly after you hand fit them in the manner just described.

SOLDERING AND BRAZING

As an Opticalman, you may occasionally need to join metals by either soft soldering, silver soldering, or brazing. Soft soldering is done at temperatures below 800°F with lead alloy solder. Silver soldering and brazing require a temperature above 800°F to melt the silver solder or brazing rod.

Optical instruments and related fittings and test equipment are manufactured from brass, bronze, cast iron, steel, stainless steel, or aluminum. Information on the repair of damaged aluminum components is outside the scope of this manual. However, we shall discuss the joining of other metals which you can do in the optical shop.

SOFT SOLDERING

Many optical instruments use switches and wiring for electrical or electronic circuits contained in the instruments. To make repairs, or replace defective components, you will need to know how to make or remove soldered connections.

It is also likely that you can use soft solder to manufacture special fittings or to repair a damaged instrument component. *Tools and Their Uses*, (NAVEDTRA 10085 Series) shows detailed procedures for soft soldering operations.

SILVER SOLDERING AND BRAZING

While soft soldering can be done with a small torch or soldering gun, an oxyacetylene torch is

180

needed for silver soldering and brazing. Figure 7-16 shows various tip shapes to use in this operation. Part A shows the tip to use for heating large areas, Part B shows the tip to use for heating a smaller area, and Part C shows the tip which will produce a small cone of flame for fine work.

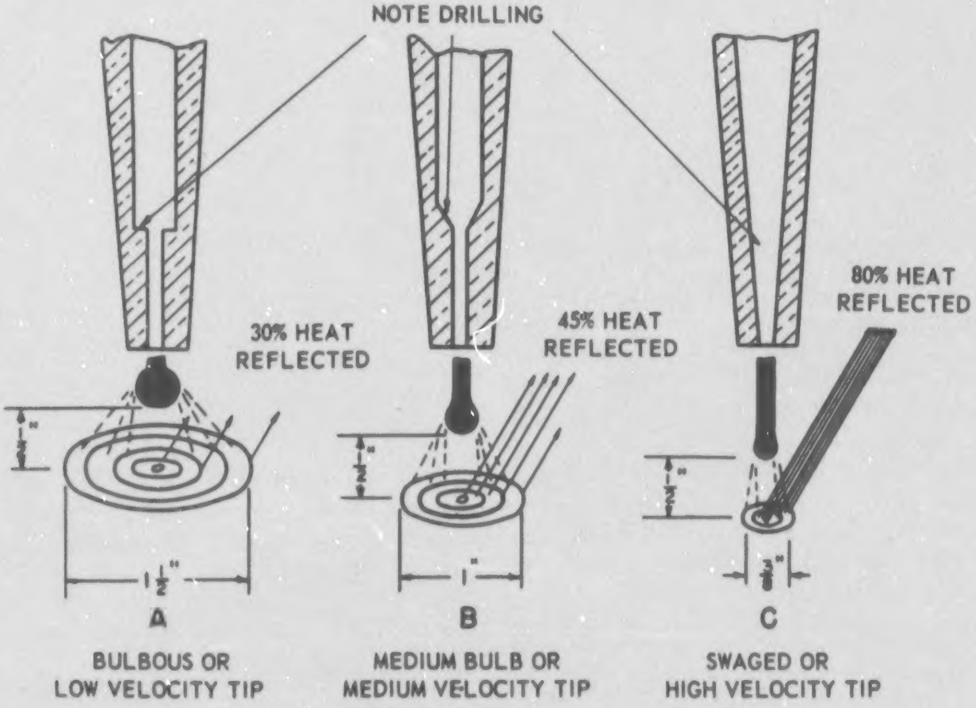
Control of heat is the most critical part of silver soldering and brazing. Factors to consider are the tip to use, regulation of oxygen and acetylene, how and where to apply heat (torch manipulation), and the thickness of parts to be joined. Your shop supervisor is the best source of information and assistance until you have enough experience to handle the job yourself.

Heat flow in metals must be considered whenever you silver solder or braze. Also important is the distance between elements to be joined. Figure 7-17 shows how heat must be applied to join two components with varying separations.

A soft metal, like copper, requires a longer application of heat than a harder metal steel because the softer metal is more conductive (heat flows away from the source more rapidly). Another problem you will encounter is joining a large casting with a smaller piece of tubing or bar stock. You must manipulate your torch to keep both pieces at the correct temperature to cause the molten filler metal (silver solder or brazing rod) to flow between them. Figure 7-18 shows how filler metal flows toward the heat.

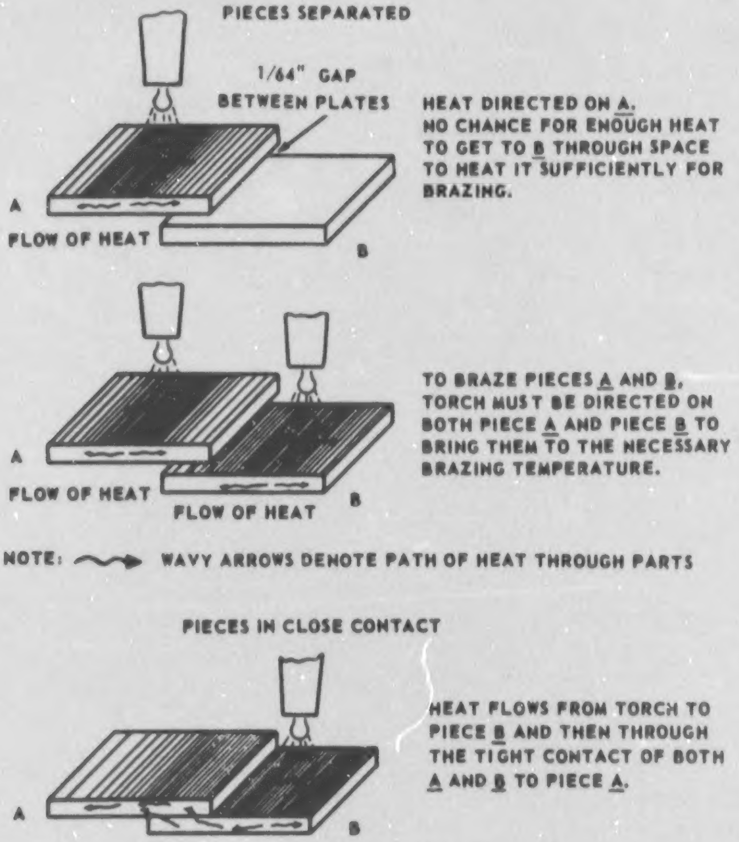
Except for cast iron, ~~silver~~ soldering or brazing can be used to join brass, copper, bronze, steel, or stainless to similar metals or others listed. Brazing alone works best for cast iron.

There are a number of different silver solder and brazing filler metals available. The commonly used filler metal alloys include silver, copper, zinc, phosphorus, cadmium, and nickel. The percentage of the various metals included in any filler metal determines the color of the alloy, its strength, melting point, and flow point.



11.115

Figure 7-16.—Tip designs.


PIECES SEPARATED
1/64" GAP BETWEEN PLATES
HEAT DIRECTED ON A. NO CHANCE FOR ENOUGH HEAT TO GET TO B THROUGH SPACE TO HEAT IT SUFFICIENTLY FOR BRAZING.
A
FLOW OF HEAT
B
TO BRAZE PIECES A AND B, TORCH MUST BE DIRECTED ON BOTH PIECE A AND PIECE B TO BRING THEM TO THE NECESSARY BRAZING TEMPERATURE.
A
FLOW OF HEAT
FLOW OF HEAT
B
NOTE: WAVY ARROWS DENOTE PATH OF HEAT THROUGH PARTS
PIECES IN CLOSE CONTACT
HEAT FLOWS FROM TORCH TO PIECE B AND THEN THROUGH THE TIGHT CONTACT OF BOTH A AND B TO PIECE A.
A
B

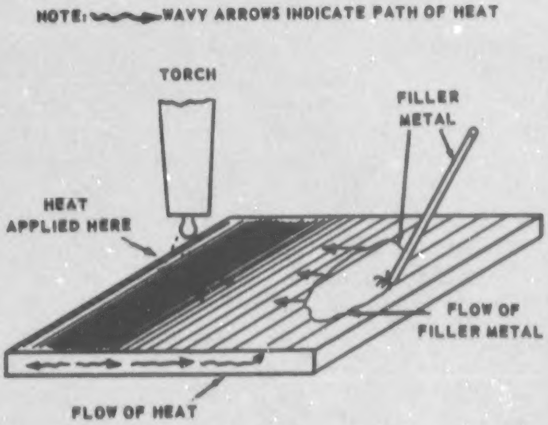
11.118

Figure 7-17.—Flow of heat.

FLUXES

All silver soldering and brazing operations require the use of a flux. The flux prevents oxidation of the metal surfaces and removes oxides already present. Flux also increases the flow of the filler metal and increases its ability to adhere to the base metal. It brings the filler metal into immediate contact with the metals being joined and permits the filler to penetrate the pores of the metal, thus forming a strong joint. Prior to applying flux to any joints, be sure the parts are thoroughly cleaned, degreased, and polished.

The fluxes used by the Navy are selected in accordance with specifications to meet the



11.119

Figure 7-18.—Flow of molten filler metal.

requirements for using various alloys. For best results, a flux must become active at a temperature slightly below the melting point of the filler metal and must remain fluid at the brazing temperature. If you use the wrong flux with any particular filler metal, you could possible overheat the flux and destroy the adherence of the filler metal.

Flux comes in three forms: liquid, paste, and powder. When used either in paste form or in liquid form, the flux is applied with a brush to both parts of the joint; best results are obtained when the filler metal also is given a coat. Use a circular motion in brushing it on, and let the flux extend outside the joint or fitting. Brushing the flux on with a circular motion gives a uniform coating and lessens the possibility of bare spots that will oxidize during heating. Fluxing the filler metal can be done by heating the filler rod and dipping it into the flux. Sufficient flux to do the job will stick to the hot rod.

When applying flux or assembling the parts, avoid handling the polished parts of the joint or you will defeat the purpose of cleaning. Flux should always be applied as soon as a joint area is cleaned even though it will not be joined immediately.

SILVER BRAZING TECHNIQUES

The process by which heat flows from molecule to molecule through a metal is called CONDUCTION. Conduction takes place quite rapidly in most metals, but air is a very poor conductor of heat. Therefore, if two pieces of metal that are to be joined are not in contact with each other, each piece must be heated separately. If the two pieces are in contact with each other, you can heat them both by applying heat to one of them; the second piece will be heated by conduction. When two pieces of different metals are to be joined by silver brazing, the difference in heat conductivity of the two metals must be considered.

The filler metal and the flux used in silver brazing cannot occupy the same space at the same time. Therefore, a clearance must be provided in the setup of the joint so that the filler metal can flow in and the flux can flow out when the filler metal reaches the bonding temperature.

The STICK-FEED METHOD, shown step-by-step in figure 7-19, is most often used in the optical shop.

In this method, the judgment of the individual performing the job determines when both parts are properly heated and when to feed the filler metal. If is also left to his judgment to determine when sufficient filler metal has been fed into the joint to completely fill the space between the two parts being joined. Skillful torch manipulation is necessary to apply heat to the proper component at the correct time to form a perfect joint. Overheating will burn out the flux and destroy the joint. After joining is satisfactorily completed, flush the joint with warm water to remove the flux residue.

HEAT TREATING AND TEMPERING

As an Opticalman, you will work with metals at various times while working on optical instruments. Thus, you should be familiar with types of metals, the properties of metals, and the heattreating processes for the most common metals.

The metals with which you work can be divided into two general classifications, ferrous and nonferrous. FERROUS metals are those that are composed primarily of iron. NONFERROUS metals are those that are composed primarily of some element or elements other than iron. Nonferrous metals or alloys sometimes contain a small amount of iron as an alloying element or as an impurity.

Metals and alloys vary widely in their characteristics or properties. Chemical properties involve the behavior of the metal in contact with the atmosphere, saltwater, or other environments. Physical properties relate to color, density and weight, magnetic qualities, electrical conductivity or resistance, and heat conductivity. Mechanical properties relate to load carrying ability, wear resistance, and elasticity.

The various properties of metals and alloys have been determined in the laboratories of manufacturers and are tabulated and indexed by various engineering societies interested in metallurgical development. Charts which give properties pertaining to a particular metal or alloy are published in such reference books as the *Metals Handbook*. The charts provide information on the physical and mechanical properties which have been determined.

What are the properties an Opticalman needs to understand about the metals most commonly used? They include the mechanical properties of (1) hardness, (2) toughness, (3) ductility, (4) malleability, (5) brittleness, and (6) tensile strength. Following is an explanation of the meaning of these terms.

The HARDNESS of a metal is the property that resists scratching, denting, cutting, or erosion. It may also be defined as the ability of the metal to resist penetration. A piece of lead, for example, can easily be scratched with a knife. But it would be difficult to mark a piece of steel in this manner. The reason is that steel possesses the property of hardness which provides resistance to scratching and cutting.

TOUGHNESS is the property of a metal that withstands shock loading without breaking. It is thus related to strength and to ductility. Usually, the hardness of a metal increases as the toughness decreases.

DUCTILITY is the property that renders a metal capable of being drawn into wire form. In other words, when the metal is stretched, it elongates rather than breaking.

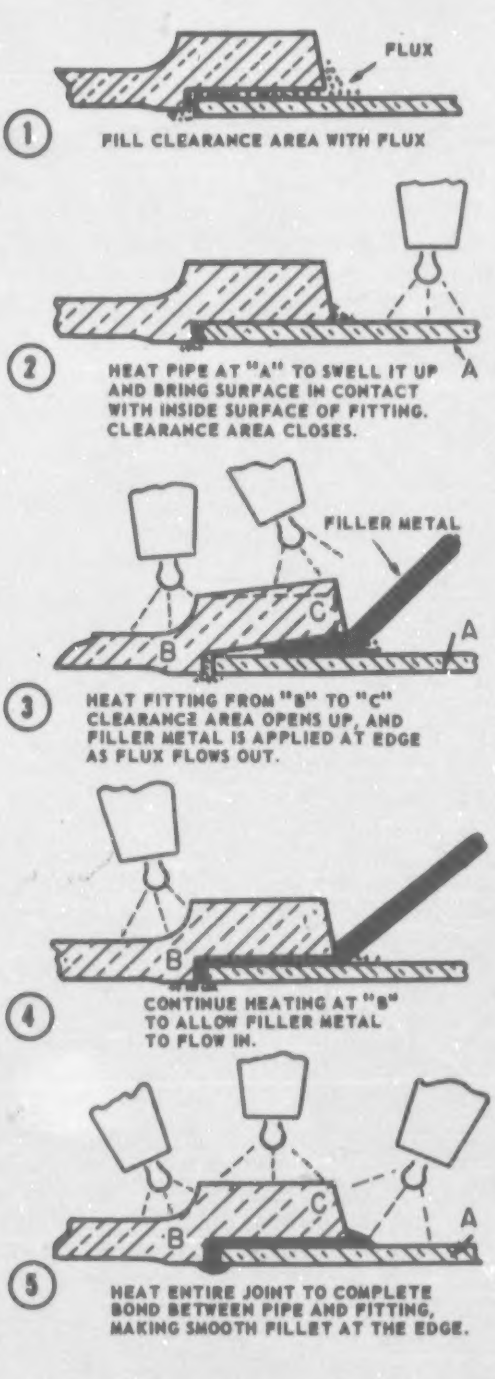
MALLEABILITY is the property of metal that permits it to be rolled, forged, or hammered into sheets without cracking or breaking.

BRITTLENESS is the tendency of a metal to break with little or no prior deformation. Hard materials are often brittle, but a metal or alloy which is properly heat treated can be hard without brittleness.

TENSILE STRENGTH is the property of a metal which resists forces that tend to pull the metal apart. It is measured in terms of pounds per square inch which represents the pull that must be exerted on a cross-sectional area to break the metal.

CORROSION RESISTANCE, though not a mechanical property, is also of primary importance. Corrosion resistance is the property that withstands chemical or electrochemical attack by air, moisture, soil, or other agents.

The various mechanical properties described may be desirable at times and undesirable at


FLUX
①
FILL CLEARANCE AREA WITH FLUX
②
HEAT PIPE AT "A" TO SWELL IT UP AND BRING SURFACE IN CONTACT WITH INSIDE SURFACE OF FITTING. CLEARANCE AREA CLOSES.
A
FILLER METAL
C
B
A
③
HEAT FITTING FROM "B" TO "C" CLEARANCE AREA OPENS UP, AND FILLER METAL IS APPLIED AT EDGE AS FLUX FLOWS OUT.
B
④
CONTINUE HEATING AT "B" TO ALLOW FILLER METAL TO FLOW IN.
C
A
B
⑤
HEAT ENTIRE JOINT TO COMPLETE BOND BETWEEN PIPE AND FITTING, MAKING SMOOTH FILLET AT THE EDGE.

11.124

Figure 7-19.—Feed-in method of silver brazing.

other times, depending on the purpose for which the metal is to be used. But resistance to corrosion is always a highly desirable characteristic.

FERROUS METALS

A few examples of ferrous metals are pig iron, cast iron, ingot iron, and wrought iron. Carbon steel and the various alloy steels–structural as well as tool steel–are also considered as ferrous metals since they are composed of iron to which relatively small percentages of carbon and other elements have been added as alloys.

The term cast iron may be applied to any iron in which the carbon alloy is more than 1.7%. Cast iron has high compressive strength and good wear resistance, but it lacks ductility, malleability, and impact strength.

Of all the different metals and materials which you will use while in the Navy, steel is by far the most important. Steel is manufactured from pig iron by decreasing the amount of carbon and other impurities present. About 15 pounds of manganese, an indispensable addition in the production of steel, is added to each ton of pig iron.

Most of the steel you use will be in the form of structural shapes, such as sheet, tube, and bar. The types of structural steel are: mild steel, medium steel, high tensile steel, special treated steel, and stainless steel.

Mild steel is used when structural strength is of no great importance and when a great deal of flanging, shaping, and other shop operations are involved.

Medium steel is similar to mild steel in its workability. But it is harder and stronger than mild steel and is used when structural strength is required.

High tensile steel, usually referred to as RTS, contains small additions of various alloys that give the steel extra hardness and toughness.

Special treated steel, known as STS, contains a small percentage of chromium-nickel. It has been specially treated to obtain hardness and toughness.

Stainless steel, referred to as SST, is generally designated by the percentage of chromium and nickel. For example, an 18-8 stainless is an alloy containing 18% chromium and 8% nickel.

NONFERROUS METALS

As an Opticalman you may work with various types of nonferrous metals. Some of the major types and their uses are discussed in this section.

Copper and copper alloys rank high among commercial metals with respect to desirable properties. Copper is ductile, malleable, hard, tough, strong, wear resistant, machinable, and weldable. Also, it has high tensile strength, fatigue strength, and thermal and electrical conductivity. Copper is easy to work and, although it becomes hard when worked, it can easily be softened (annealed) by heating it to a cherry red and then letting it cool. Annealing is the only heattreating procedure that is applied to copper.

Zinc is used often as a protective coating, known as galvanizing, on steel and iron. Zinc is also used in soldering fluxes, in die castings, and as an alloying element in making brass and some bronze.

Tin has many important uses as an alloying element. Remember that it can be alloyed with lead to produce soft solders. Alloyed with copper, it produces bronze. Tin base alloys have a high resistance to corrosion; they also have a low fatigue strength, and a compressive strength which will accommodate light or medium, but not heavy loads.

Tin, like lead, possesses a good resistance to corrosion. It has the added advantage of being nonpoisonous. But when subjected to extremely low temperatures, tin has a tendency to decompose.

Aluminum is easy to work and has a good appearance. Although light in weight, it has a high strength per unit weight, but its tensile strength is only 1/3 that of iron, and 1/5 that of annealed mild steel. In its pure state, aluminum is soft and has a strong affinity for gases. The use of alloying elements overcomes these disadvantages.

True brass is an alloy of copper and zinc. Additional elements–aluminum, lead, tin, iron, manganese, or phosphorus–may be added to give the alloy specific properties.

Bronze made of 84% copper and 16% tin was the best metal available before steelmaking techniques were developed. Many complex bronze alloys, containing additional elements such as zinc, lead, iron, aluminum, silicon, and phosphorus are now available.

Monel is an alloy in which nickel is the major element. It contains from 64% to 69% nickel, about 30% copper, and small percentages of iron, manganese, and cobalt. It is harder and stronger than either nickel or copper and has high ductility. Monel has many of the qualities of stainless steel, which it resembles in appearance, and its strength and high resistance to atmospheric corrosion make it an acceptable substitute for steel in a system or service where atmospheric corrosion resistance is of primary importance.

HEATTREATING PROCESSES

Metals in a solid state can be heated and cooled to change or improve a physical or mechanical property or a combination of properties. A metal part is heat treated to make it softer, more ductile, stronger, harder, or more resistant to wear. These properties are developed as needed to improve the usefulness and safety of a part for a definite purpose. No one heattreating operation can produce all these characteristics, and the improvement of some properties is gained at the expense of other properties.

There are different forms of heattreating. Common forms used by the Navy include: annealing, normalizing, hardening, tempering, and stress relieving. The particular process used is determined not only by the physical properties to be developed or modified, but also by the composition of the metal. Ferrous metals may be hardened, tempered, annealed, and normalized. Most nonferrous metals can be annealed and many can be hardened, but they are NEVER tempered or normalized. (For nonferrous metals, the hardening process is usually referred to simply as heat treatment.)

While all heattreating processes are similar in that they involve heating and cooling, they differ in the temperatures to which the metals are heated, the rate of cooling, and the cooling medium. In addition, some of these processes not only effect changes in physical properties, but also alter the surface composition of the metal.

For all metals, time and temperature are the important factors in the heattreating operation. Usually, the atmosphere surrounding the metal during heating, or during heating and cooling, is also critical.

Annealing

Two main purposes of annealing are (1) to relieve internal strains, and (2) to make a metal soft enough for machining. Practically all metals, ferrous and nonferrous, may be annealed, and no elaborate equipment is essential. It is possible to produce good anneals by using a heating torch or a furnace. The basic process consists of heating the metal to a specific temperature, holding it at that temperature for a specified length of time (soaking), and then cooling it to room temperature. Both the temperature of the operation and the rate of cooling depend upon the metal being treated and the purpose for which it is to be used.

Cast iron ordinarily must be heated to a point between 1400° and 1500°F. Pure aluminum can be annealed at temperatures from 625° to 700°F, but aluminum alloys require somewhat higher temperatures, depending upon their composition. Pure copper can be annealed at temperatures from 800° to 1200°F. Most brasses (copper-zinc alloys require annealing temperatures of from 475° to 650°F. Nickel-chromium alloys, which can withstand extremely high temperatures without appreciable damage, must be heated to annealing temperatures between 1800° and 1950°F.

Pure aluminum can be cooled in air; pure copper can be cooled in air, or quenched in water. Steel must be furnace-cooled, and the cooling rate must be kept slow to produce maximum softness.

In annealing, avoid overheating the metal being treated. Overheating will cause increased grain size. There is also danger of burning the metal and, in ferrous metals, decarburizing the surface if a protective atmosphere is not provided.

Normalizing

Normalizing is a heattreating process similar to annealing, but it is applied to ferrous metals only. Normalizing refines internal grain structure and relieves stresses and strains caused by welding, forging, uneven cooling of castings, machining, and bending. When steel is to be hardened, it is advisable to normalize it first; low carbon steels generally do not require normalizing, but a normalizing treatment will cause no harmful results.

The process of normalizing–like other heat treatment processes–consists of three steps: heating the metal to a specified temperature, soaking it (that is, holding it at this temperature), and cooling it. The holding time depends upon the thickness of the metal, but must be long enough to allow for uniform heating throughout. The metal should be allowed to cool evenly to room temperature in still air.

Hardening and Tempering

The primary purposes of hardening operations are to harden metal and, at the same time, increase the tensile strength. In steel, however, the hardening process increases brittleness, and the rapid cooling of the metal from the hardening temperature sets up severe internal stresses. To reduce brittleness and to relieve internal stresses, steel must be tempered after it has been hardened. Although hardening and tempering are separate steps in the heat treatment of a tool steel, the value of each procedure depends upon the other.

The hardening treatment for most steels consists of heating to the correct temperature and then rapidly cooling it in oil, water, or brine. A point to remember is that too rapid a cooling rate will increase the danger of cracking or warping. The addition of alloys permits a slower rate of cooling, and several steels (high-speed tool steels) may be cooled in air. Cooling (quenching) in oil, freshwater, or brine firmly fixes the structural changes which occurred during heating, and thus causes the metal to remain hard.

If allowed to cool too slowly, some metals will lose their hardness. On the other hand, to prevent too rapid quenching–which would result in warping and cracking–it is sometimes necessary to use oil instead of freshwater or brine for high carbon and alloy steels. (NOTE: Water or brine gives a faster quench but does not necessarily increase hardness. Hardness is dependent upon the type of steel used with the correct quenching medium; an oil hardening steel will not be harder if quenched in brine.)

In cooling, you have to bring carbon steel to a temperature somewhat below 1000°F in less than 1 second. From this point downward, a rapid cooling rate must still be maintained. Alloys added to steel increase this 1-second limit for lowering the temperature; therefore, alloy steels can be hardened in a slower quenching medium.

TEMPERING, also called DRAWING, is a process generally applied to steel to reduce brittleness and relieve stresses developed during the hardening process. Tempering always follows, never precedes, hardening. It differs from annealing, normalizing, and hardening in that the temperatures are always BELOW the red hot point.

As it reduces brittleness, the tempering process also softens the steel. One property must be sacrificed to some extent so that another property may be improved. High-speed steel is an exception, since tempering high-speed steel increases its hardness to a limited extent.

Tempering is done by heating the hardened steel to a temperature below the critical range, holding this temperature for a sufficient time to penetrate the whole piece, and then cooling the piece rapidly in water, oil, or air. The tempering temperature for hardened steel is determined by the degree of hardness and toughness desired.

Tools with cutting edges are not tempered above 650°F. The hardness required for penetration is lost if a hardened steel is heated beyond this temperature. However, the toughness and shock resistance of the steel improves as it is reheated beyond 650°F. When reheats beyond 650°F are used, the operation is frequently called TOUGHENING. You will soon learn, by trial, the temperature at which a tool must be tempered.

The following list gives the temperature for tempering various plain carbon steel tools as well as the color of the heat:

Tool	Heat Color	°F
Hammer faces, machine cutting tools	Pale yellow	400
Taps and dies	Light straw	460
Punches, reamers, dies, knives	Dark yellow	480
Twist drills	Brown yellow	500
Drift pins, punches	Brown purple	520
Cold chisels	Purple	540
Screwdrivers, springs	Dark purple	550

The following description of a common method used to harden and temper chisels will help to clarify the meaning of hardening and tempering. Bring 2 1/2 to 3 inches of the cutting edge of the tool up to hardening temperature (red hot). Then, using tongs to hold the chisel, quench by plunging 1 1/2 to 2 inches of the heated end into the quenching medium. Jiggle the tool rapidly using an up-and-down, forward-and-backward motion, and as you do make sure you keep the point immersed 1/2 inch in the quenching medium.

When the metal has cooled to a black heat (900° to 950°F in about 1 second), remove the tool from the quench tank, quickly polish the tapered end with an emery board, and watch the temper color "run out" until the desired color appears (usually purple to dark blue). Then quench the entire tool to temper it.

It is well to remember that every chisel you see is not a water-hardened chisel. Many are manufactured from special alloys and are oil-hardened. Most chisels of this type have directions for treating stamped on the shank as follows: 1350W 400 or 1600 O. The first means to heat to 1350°F, quench in water and temper at 400°F. The second means to heat to 1600°F, and quench in oil. It is not necessary to temper this tool, as it is a special alloy. Other alloy chisels will have different directions stamped on the shank. Generally, it is safe to assume that an unmarked chisel is a carbon steel water-hardened tool.

Stress Relieving

Stress relieving is a heattreating process in which uniform heating is essential, but the temperature to which the part is raised is not as high as that required for annealing and normalizing. The purpose of stress relieving, as the name implies, is to relieve stresses developed in metals during mechanical working or solidification from a molten mass.

Stress relieving is done by heating the metal slowly and uniformly to a predetermined temperature. The rate of heating should not be less than 400°F per hour for most metals. When the metal attains the desired temperature, hold or soak it at this temperature no less than 1 hour for each inch of thickness of the thickest section. Then allow the part to cool very slowly to room temperature. The cooling rate should not exceed 200°F per hour for any metal. Since the majority of stress relief occurs during the first hour after the part attains the proper temperature, it is essential that you count the hold time from the time the metal, not the furnace, reaches the stress relieving temperature. Remember, slow cooling is essential. If the part is cooled rapidly, new internal stresses develop, defeating the purpose of the treatment. Typical practices for stress relieving common metals are presented in table 7-1.

Table 7-1.—Stress Relieving Data

Material	Temperature (°F)	Hold time (hours per inch thickness)
Gray cast iron	950	1
Low carbon steel	1,150	1
Carbon-molybdenum steel	1,250	2
Chromium-molybdenum steel:		
(0.5 Cr-0.5 Mo)	1,250	2
(2 Cr-0.5 Mo)	1,325	2
(9 Cr-1 Mo)	1,400	3
Copper	300	1/2
Brass:		
(70 Cu-30 Zn)	500	1
(60 Cu-40 Zn)	375	1/2
Bronze:		
(90 Cu-10 Sn)	375	1
Stainless steel	1,550	2
Monel	550	2

CLEANING AND PAINTING

Having completed all repairs to your instrument, you are now ready to do the essential cleaning prior to painting. Reclean all parts on which you made repairs to remove traces of moisture, dirt, metal chips, grease, and corrosion. If a part does not require painting, put it in the container with other cleaned parts of the instrument.

Before you can successfully paint any metal object, you must get it thoroughly clean. If the surface is covered with rust, dirt, or grease, the paint cannot reach the metal. It forms a loose coat that chips or peels off. If you paint over grease or oil, it will probably mix with your paint, and the mixture will dry very slowly, or not at all.

CORROSION REMOVAL

When a part is corroded, thoroughly clean it so the paint will adhere and give a good finish. Use approved commercial compounds. Always follow the manufacturer's instructions when you use these products, and protect yourself by following safety precautions.

If you do not have an approved corrosion removal compound, you can make some (for different metals) by using the following formulas:

CAUTION: Do NOT handle chemicals until you understand the safety precautions which pertain to them. NEVER USE CORROSION REMOVAL COMPOUNDS ON BEARINGS OR GEAR TEETH.

1. To make a corrosion removal compound for cast iron and steel, use a 50% solution of sulfuric acid and distilled water (about 150°F). Then dip the corroded metal parts in the warm acid for about 5 seconds, and wash them immediately in several changes of hot water.

2. You can make a corrosion removal compound for brass by using the following formula:

Water (pure, distilled)	491 cc
Sulfuric acid (concentrated)	435 cc
Nitric acid (concentrated)	72 cc
Hydrochloric acid (concentrated)	2 cc

If a corroded brass surface is bright in spots, it was probably polished and protected with clear lacquer. Submerge the part in paint remover and then rinse it with hot water. Continue by dipping the part in the correct amount of the corrosion removal solution for 4 or 5 seconds, rinsing it in water, drying thoroughly with an airhose, and applying at least one coat of clear lacquer before the surface oxidizes. NOTE: Do NOT use lacquer if the part is to be painted and not polished.

3. To clean corrosion from aluminum, dip it for 5 to 10 seconds in a 10% solution of sodium hydroxide (lye) at a temperature of about 150°F and wash the lye off immediately with hot water.

You can also use some nonchemical methods for removing corrosion and giving a bright, smooth finish to metal parts. These methods involve wire brushes, buffing wheels, and abrasive cloth.

REMOVING CORROSION WITH A WIRE BRUSH.–There are two types of wire brushes which are used to remove corrosion from metal–rotary-power and hand.

CAUTION: To prevent damage to your eyes, always wear goggles to protect them from flying wire. Do NOT use a power driven brush on a bearing surface or an engraved part.

To use a rotary-power wire brush, maintain enough pressure to force the moving wire bristles into the corrosion, and use a slow, even movement. Start in the center of the part and move toward the edges to ensure thorough cleaning of the edges. Use a fine hand wire brush on delicate parts and the inside corners of irregular pieces.

REMOVING CORROSION WITH A BUFFING WHEEL.–A buffing wheel gives a part a brighter, polished finish than a wire brush or emery cloth, but it will not remove heavy corrosion. To speed up the buffing process, clean the parts first in a corrosion remover or use a wire brush. Do not use these wheels on large areas, but use them to polish small irregularly shaped metal parts which must remain bright.

Use a polishing compound on the buffing wheel, and polish a part until you have the desired finish. Then remove the remains of the polishing compound with a solvent, dry the part thoroughly, and apply at least one coat of clear lacquer.

CAUTION: A buffing wheel turns at high speed, so use light pressure to avoid the heat of friction. Also, remember that a buffing wheel can pull parts out of your hand and propel them across the work space at high speed. It is also important to remember that power brushes and buffing wheels will remove metal and leave low spots on the work if you do not use steady movement and pressure.

REMOVING CORROSION WITH ABRASIVE CLOTH.–You can remove corrosion from metal with an abrasive cloth in the following manner:

1. Polish flat pieces by hand using various grades of emery cloth laid on a workbench.
2. Polish irregular pieces in a vise. Use wood or metal in the jaws of a vise to protect these pieces and secure them ONLY as tightly as necessary. It is often beneficial to wrap abrasive cloth around a file for this operation.
3. Put small, round parts of an instrument in the collet of a lathe and (with the lathe running at high speed) touch the parts lightly with emery cloth or crocus cloth just enough to get the polish desired.

NOTE: Sandpaper of various grades is used to finish wood surfaces. Metal is polished with emery cloth, crocus cloth, or wet or dry abrasives. Emery cloth is available in grades from 60 (very coarse) to 320 (fine). Wet or dry abrasives usually span 320 to 600 grit (most often used in auto paint and body shops). Crocus cloth has about the same abrasive quality as the finest metal polish.

SAFETY PRECAUTIONS FOR USING CHEMICALS

You probably learned a great deal about safety precautions in basic naval training courses you studied previously. The safety precautions discussed in the next section are particularly important to Opticalmen and should be repeated. Study the following rules when you work with all kinds of chemicals. If you remember them, you may be able to prevent injury or death.

1. DIRECTIONS FOR USE: Study the directions on the container before using any chemical. Do not mix chemicals improperly, or in incorrect proportions; they may explode or release deadly fumes.

WARNING: NEVER MIX CHEMICALS AT RANDOM, OR PLAYFULLY, JUST TO FIND OUT WHAT HAPPENS. IF YOU DO, YOU MAY NOT LIVE LONG ENOUGH TO SATISFY YOUR CURIOSITY. ALWAYS WORK WITH CHEMICALS IN A WELL VENTILATED AREA TO AVOID BREATHING DANGEROUS FUMES.

2. LABELS: Keep labels on containers of chemical intact. If you notice that a label is coming loose, glue it back in place. Then coat the label.

WARNING: NEVER USE A CHEMICAL FROM AN UNLABELED CONTAINER–DISPOSE OF IT IMMEDIATELY.

3. WATER AND ACID: If you must mix water and acid, POUR THE ACID VERY SLOWLY INTO THE WATER. If you pour water into acid, the mixture will boil over and burn everything it touches.

4. CLEANLINESS: Keep chemicals and their containers clean, as well as all equipment, supplies, and spaces you use when handling chemicals. Even a small amount of contamination may ruin your work.

5. CHEMICAL POISONING: Many chemicals are poisonous, and some of them can burn your clothes and skin. CAUTION: Wear rubber gloves, a rubber apron, and goggles whenever you work with chemicals. Remember the antidotes for poisoning and chemical burns. This knowledge may save a life. Even after you administer an antidote or neutralize a chemical, report to sick bay.

TREAT ACID BURNS AS QUICKLY AS POSSIBLE. Wash off the acid with an abundance of water, and then wash your hands under a spigot if they were involved. Continue by neutralizing all remaining acid with lime water (calcium hydroxide), a mixture of equal parts of lime water and raw linseed oil, or a paste of baking soda and water. REMEMBER THIS: Baking soda is a base and it neutralizes acids. If acid gets in your eyes, wash it out with cold water and then wash your eyes with weak lime water.

WASH ALKALI BURNS WITH PLENTY OF COLD WATER; then neutralize remaining portions of the alkali with vinegar or lemon juice. Weak acids, such as vinegar or lemon juice neutralize bases (alkalies) or caustics such as lye.

Antidotes for Poisons

Study these antidotes carefully; better still, memorize as many as possible.

ACETIC ACID.–Use an emetic to cause vomiting. Magnesia, chalk, soap, oil, mustard, and salt are emetics. A quick method for making a good emetic is to stir a tablespoon of salt or mustard into a glass of warm water.

HYDROCHLORIC, NITRIC, AND PHOSPHORIC ACID.–Use milk of magnesia, raw egg white, cracked ice, or a mixture of baking soda and water as an antidote for poisoning by these acids.

CARBOLIC ACID.–Some good antidotes for carbolic acid are: egg white, lime water, olive or castor oil with magnesia suspended in it, zinc sulfate in water, cracked ice, pure alcohol, or about 4 ounces of camphorated oil. Remember particularly egg white, lime water, and cracked ice, for they will most likely be readily available.

ALKALIES (SODIUM OR POTASSIUM HYDROXIDE).–Good antidotes for poisoning by strong alkalies are vinegar, lemon juice, orange juice, oil, or milk. You can easily remember these antidotes.

DENATURED ALCOHOL.–Antidotes for poisoning by denatured alcohol are emetics, milk, egg white, and flour and water. If breathing stops, give artificial respiration.

IODINE.–Give emetics or plenty of starch or flour stirred in water.

PAINT REMOVAL

When you are to repaint a surface that is already painted, you will usually need to remove the old paint first (stripping). Apply a commercial paint remover by brushing it onto the painted surface. (After you have used a brush for paint remover, do not use it again for any other purpose.) Brush-on paint remover dissolves synthetic-bristle brushes, so use a natural-bristle brush.

Leave the paint remover on the part as long as necessary for it to dissolve the paint, then rinse off the loosened paint in running water. To remove all traces of paint remover, which sometimes leaves a waxy film, scrub the parts in strong soapy water, rinse in hot water, and blow dry. Because it is difficult to wipe brush-on paint remover out of holes and corners, you will experience some difficulty in using it.

If an instrument has a good paint job except for a few chips on the corners, you can sometimes dress the chipped areas with fine emery cloth, scrub and dry the surfaces, and then paint the instrument.

Immersion type paint and carbon removers are available through Navy supply channels, and also commercially. They are designated as SUPER cleaners. Besides stripping paint, they remove heavy carbon, grease, varnish, and sticky gums.

You will get best results with a paint and carbon remover by putting at least 10 gallons in a stainless steel tank and soaking the parts in it as long as necessary. Then wash each part with hot water, remove the water with a compressed airhose, and bake it briefly in an oven. It is then ready for painting.

TYPES OF PAINT

Many aluminum parts have a very smooth, hard finish which appears to be painted. This finish is called ANODIZE, and it is deposited by an electrochemical process. If an anodized finish becomes scratched, corrosion will start and the part will require painting after the corrosion is removed.

The paint you will be using is usually either gray or black. It is available in dull, semigloss, gloss, and also wrinkle finish. Lacquers and enamels are preferred. Dull, flat black paint is used to cut down surface reflections, and it is also used to kill internal reflections on the inside of optical instruments. Paints which give a semigloss appearance and a hard, durable finish are used on parts which receive considerable handling and on such small articles as eyepiece focusing rings, knobs, handles, and pointers. You will generally use a semigloss black finish paint on most optical instruments.

Grey or black wrinkle paint is often used on body castings of large instruments or on smaller portable navigation instruments. Wrinkle paint offers the most durable finish available.

Always use clear lacquer on parts subject to corrosion, but which are not painted, to protect their high polish.

CAUTION: Never cover enamel with lacquer because the lacquer loosens the enamel from its base and causes it to blister.

A baking enamel of high quality gives a hard, durable finish, but air-dried enamel is good for touching up or painting an instrument which cannot be subjected to heat in a baking oven. Acrylic enamels sprayed from aerosol cans are widely used in optical shops. Results are not so good as enamels sprayed from a gun, but such paints are satisfactory for most instrument finishes, and they are easy to use.

Lacquers have one outstanding characteristic: they dry quickly, but they cannot resist chemicals and are therefore not as durable as enamels.

PREPARING PAINT

Prepare lacquer, enamel, or wrinkle paint in the same manner for use in a spray gun, as follows:

1. Stir the paint thoroughly to mix the pigment back into the liquid used to suspend it. Unless you do this, the paint will not cover surfaces with uniform luster or color.
2. Thin thick paint before you put it into a spray gun; otherwise, it will clog the gun or give you an unacceptably thick finish. Follow the manufacturer's instructions when you thin the paint.

Do not add more than 20% of thinner to the paint, lest you get it so thin that it will not cover properly. It is best to add small amounts of thinner and stir thoroughly until the desired consistency is reached. Dip a pencil vertically into the paint and then withdraw it. If the consistency is correct for spraying, the paint will run off the pencil in a smooth, thin stream.

3. When you have the paint properly thinned for spraying, strain it through several thicknesses of cheesecloth or medical gauze to eliminate lumps of undissolved pigment, dirt, and any other particles which could clog the spray gun and produce a poor finish.

Paints and their thinners are flammable, and some are explosive; so use a spray booth with an explosion-proof exhaust fan. To prevent spontaneous combustion, put rags used for wiping paints, oils, thinners, etc. in a container with a self-closing cover, and dispose of them completely as soon as practical. Stow paint materials in a locker which will not tip over, and at a temperature less than 95°F but above freezing.

CAUTION: Permit no smoking in the sprayroom, and have a CO_2 fire extinguisher available.

INSTRUMENT PAINTING

The three reasons for painting metal parts of optical instruments are as follows (in order of importance):

1. To protect the metal from rust and corrosion. This is most important for instruments used aboard ship, where salt spray and damp, salty air quickly corrode unprotected metals.
2. To kill reflections. The glare of bare metal in the sunlight is very annoying to the user of an optical instrument, and under some conditions a brilliant reflection from a metal surface may reveal the observer's presence to an enemy.
3. To improve appearance. A good-looking optical instrument creates a good impression on all who see and use the instrument.

Once a surface is clean and otherwise ready for painting, you must mask areas where paint is not desired, such as bearing surfaces, screw threads, and the interior of the instrument. Be very careful when masking these areas. You must NOT touch a prepared surface with your fingers. Be sure to trim excess masking tape with a razor blade or sharp knife.

To paint screwheads, punch small holes in a cardboard box and insert the screws. This not only keeps paint off the body of the screw, but also helps you avoid losing these small parts.

Other small parts to be painted can either be laid on pieces of cardboard or you can suspend them from wire hooks.

REMEMBER: Once a part is clean, you do not want to touch it or allow it to touch anything else until after the paint is dry.

Before you use a spray gun for the first time, seek good information concerning its operation, or closely follow the manufacturer's instructions for its use. Check the spray gun for cleanliness. If it is dirty or has old paint on the inside, disassemble it completely and soak the metal parts in a paint remover. Clean the gaskets in lacquer thinner. CAUTION: Paint remover will ruin the gaskets. When you reassemble the spray gun, lubricate all moving parts and make sure the gun is clean.

NOTE: Your air supply should have an air pressure and reducing valve with a water and oil trap (and filter) which works properly all the time. Drain the trap regularly. If water and/or oil get into your spray gun and paint, it will ruin the appearance of your work.

The air pressure to use for spray painting should be from 10 to 25 pounds per square inch. The pressure to use depends on the type and consistency of the paint and size of parts to be painted. Your spray gun can be adjusted to provide a cone-shaped spray or a horizontal or vertical fan spray. You can also control the amount of paint contained in the spray with a fluid needle.

For small or irregularly shaped parts, use a light cone-shaped spray. For larger parts, adjust the gun to provide a heavier, vertical fan-shaped spray.

Hold the spray gun about 10 inches from your work and keep it moving smoothly back and forth. Be sure to carry each swing of the gun out past the end of the work before you start back to prevent piling up the paint near the edges of the work, which causes sagging. Start at the top of a surface and work down, and cover the last old lap with about half of your new lap. If you follow this procedure, your paint will uniformly cover the entire surface.

Do not apply the paint too thickly. In the first place, a thick coating will not be as durable as several thin coats. Secondly, a thick coating will sag or actually drip off the surface, which will destroy the appearance of your paint job.

When each part is painted, hang it in the oven or in a protected area for air drying. Even a space as clean as the optical shop will have some dust or lint in the air. If these foreign particles end up on a painted surface, you may have to start all over again.

After you finish a paint job with a spray gun, wipe any paint out of the vent hole for the paint cup. You can hang the gun up with paint in it if it is to be used several more times during the day. At the end of the day, or if the gun will not be used again, completely disassemble the gun and wash all parts in lacquer thinner. Then dry, lubricate, and reassemble it so that there will be no delay when you start the next day's work.

BAKING PROCEDURE

Always follow the paint manufacturer's instructions on baking and drying the paint that you use. When you do not have specific instructions, a good rule of thumb is to bake for 2 1/2 hours at 250°F.

When you intend to paint and bake instrument parts, remove all masking tape before you put the parts in the oven. If you cannot remove the tape before you bake the parts, remove it immediately upon taking the parts out of the oven. This is also a good time to apply engraver filler, commonly called MONOFILL (a soft, wax-base compound generally in crayon form) to fill in and accentuate engraved index lines and numbers. While the part is hot, the filler flows easily into an engraving. When the part cools, wipe off the excess filler with a soft cloth.

FINISH DEFECTS

Following is a list of difficulties sometimes experienced in spray painting, with the reason for each difficulty given.

FINISH REFUSES TO DRY: You neglected to remove the oil and grease from the metal surfaces of your work, or from your air supply.

FINISH SHOWS OCCASIONAL ROUGH SPOTS: There was too much dust or lint in the air or on the piece being painted.

FINISH HAS SMALL CIRCULAR MARKINGS: There was water in the airhose or water dripped or condensed on the work before it was completely dry.

FINISH SHOWS HORIZONTAL STREAKS: Your spray was too fine and the last lap had started to dry before you applied the next one, or you forgot to cover half of each old lap with the following lap (common with lacquer).

FINISH IS UNIFORMLY GRAINY: The spray was too fine, or you held the gun too far from the work, and the droplets began to dry before they hit the work.

THE FINISH HAS LUMPS OR BLOBS: The spray gun or air line was dirty or you forgot to strain the paint.

THE FINISH RUNS: The consistency of the paint was too thin.

THE FINISH SAGS: You moved the gun too slowly, held it too close to the work, or adjusted the gun improperly. Generally, the coat was too heavy.

THE FINISH SHOWS ORANGE-PEEL EFFECT: The consistency of the paint was too thick, your spray was too fine, and you held the gun too far from the work.

LENS CLEANING AND CEMENTING

The Navy's standard for cleaning optical elements is: OPTICS MUST BE CLEANED TO ABSOLUTE PERFECTION.

Bear in mind that an optical instrument with components of the highest quality, arranged in the best design possible, is of little or no value if vision through it is obscured by dirty optics. This statement does not mean grime or mud; IT MEANS THE SMALLEST VISIBLE SPECK OF DUST. Even a speck on a reticle may obscure some detail of an image, and a fingerprint or film of oil will most likely blur the overall image.

For the reasons just given, you must learn the proper technique for cleaning optics, and you must then apply them with patience, care, and thoroughness. Knowledge of procedure, plus appreciation for quality work, will enable you to attain the absolute perfection required.

CLEANING EQUIPMENT

The equipment you need for cleaning optical elements includes a rubber or metal bulb syringe, several small camel hair brushes, medically pure acetone, lens tissue (soft, lintless paper), absorbent cotton, wooden swab sticks, stoppered containers for acetone, and a container to keep the cotton absolutely clean.

Pure alcohol is sometimes used as a precleaner (before using acetone). To this list you may also wish to add a special lintless cloth for cleaning optics, the best type of which is SELVYT CLOTH.

You can make a lens-cleaning swab with cotton or lens tissue. To make a cotton swab, use the end of a wooden swab stick to pick up the top fibers of the cotton. Thrust the stick into the material and rotate the stick until some fibers catch on it; then pull the captured fibers loose from the mother material. Repeat this process as often as necessary until you have a swab of desired size. Shape the swab by rotating it against a clean cloth or lens tissue.

CAUTION: Do NOT touch the tip of the swab with your fingers or lay it down on the bench top where it will pick up dirt. Do NOT use commercial cotton-tipped swabs (Q-tips); they use an adhesive that acetone dissolves. Figure 7-20 shows the step by step procedure for making a swab out of lens tissue. Swabs made in this manner are useful for picking up individual specks of dirt from a lens or reticle, using acetone as a cleaner. Make a supply of

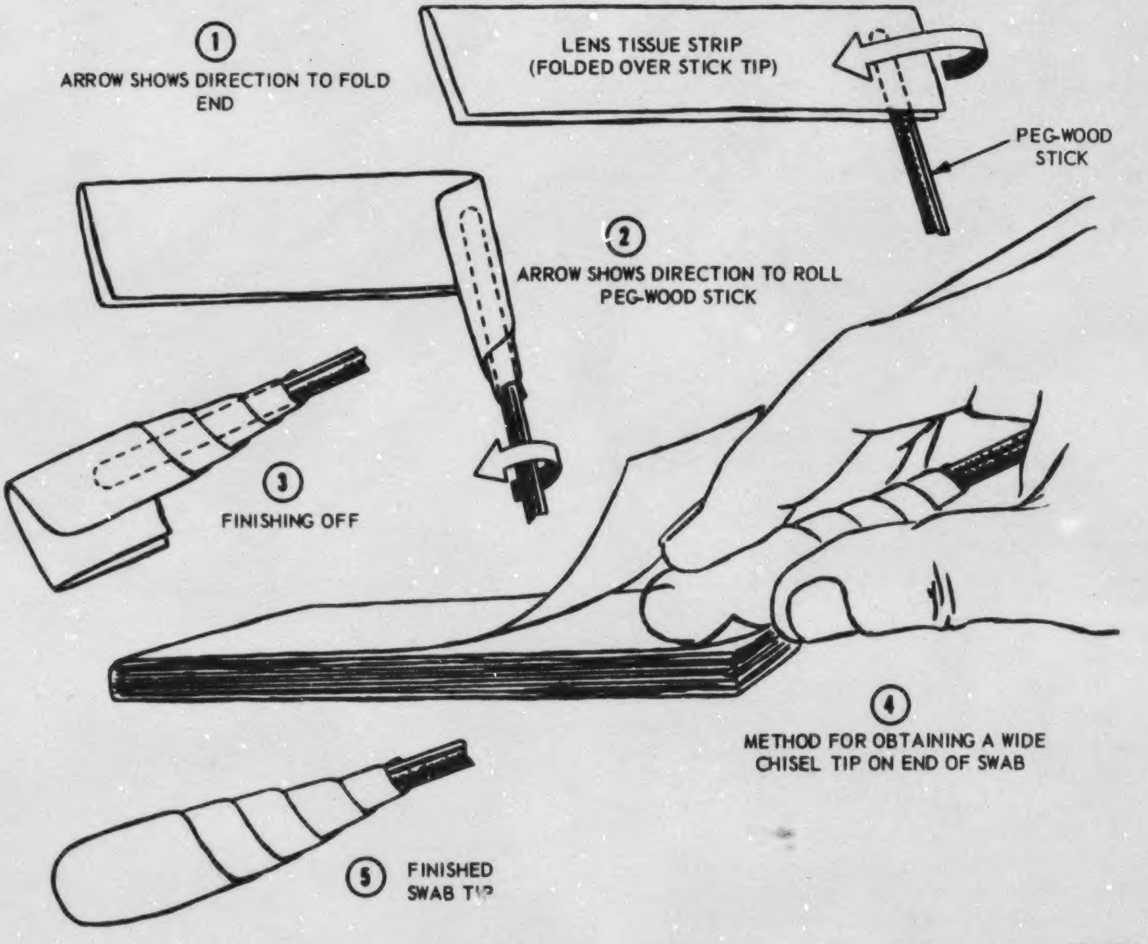

①
ARROW SHOWS DIRECTION TO FOLD END
LENS TISSUE STRIP (FOLDED OVER STICK TIP)
PEG-WOOD STICK
②
ARROW SHOWS DIRECTION TO ROLL PEG-WOOD STICK
③
FINISHING OFF
④
METHOD FOR OBTAINING A WIDE CHISEL TIP ON END OF SWAB
⑤
FINISHED SWAB TIP
137.190

Figure 7-20.—Procedure for making a lens-tissue swab.

lens-tissue strips for fabricating swabs by cutting a packet of 4 X 6-inch lens tissue down the center lengthwise so that you can remove the strips one at a time.

Press the tip of the round swab between the cover and the top tissue to obtain a flat, chisel-like cleaning tip.

You can make a large, useful lens cleaning pad by folding two thicknesses of 8 X 11-inch lens cleaning tissue along its length and bringing the two ends together. When you dampen this pad with acetone, you can clean a large area of glass quickly and effectively.

CLEANING PROCEDURE

The recommended procedure for cleaning optics is:

1. Blow all coarse and loose dust from the surface with a bulb syringe. Then brush, using quick, light strokes. Flick the brush after each stroke to dislodge the dust it picked up, and blow off newly loosened particles of dust with the bulb syringe.

2. If the element is large, use several pads of lens tissue dampened with alcohol to remove stubborn particles and oil film. Change cleaning pads or swabs frequently to prevent damage to the optic by dirt or grit. Use a cotton or lens-tissue swab on small optics, with alcohol as the cleaning agent.

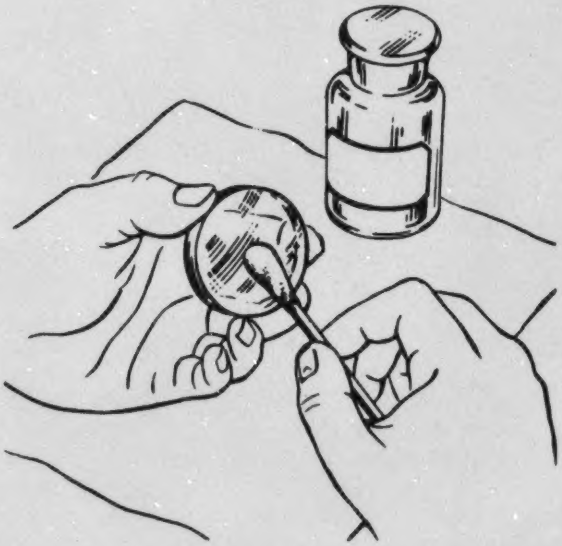
3. Finish the cleaning of the optic by using a pad or swab, dampened with a few drops of acetone, to remove traces of film remaining from precleaning. Acetone will not remove grease which must be removed with solvent, then washed in soapy water, and finally cleaned with alcohol and acetone.

CAUTION: ACETONE IS HIGHLY FLAMMABLE; KEEP IT AWAY FROM FIRE AND HEAT. Some special optical elements are made from plastics. Acetone will destroy the polished surfaces of these elements. Consult your shop supervisor or the appropriate technical manual to determine the composition of the optics. If you use a swab or pad moistened with acetone for more than 20 seconds, it leaves streaks or watermarks on the lens. Acetone evaporates quickly, and moisture in the surrounding air condenses in the swab or pad. Medically pure acetone (triple-distilled) leaves an optical surface perfectly clean and free of film when used as described.

4. As you clean an optic, swab lightly in a straight line motion, when possible, and work from the center to the edges. If you lift a damp swab from the surface of an optic, it will leave a smudge. If your acetone or swab is contaminated, it will leave streaks. Avoid excessive rubbing, since this could cause the element to become charged with static electricity. If an optic is charged, lint from the swab or lens tissue cannot be removed. The only remedy is to wash the element in warm soapy water.

Figure 7-21 shows the recommended method for holding a lens and swab. To hold smaller lenses for cleaning, you should use a lens chuck (fig. 7-13) or a retaining ring of the same diameter as the lens. Holding the lens with a chuck or retaining ring will reduce the possibility of contaminating the swab with perspiration from your fingers.

5. When you think an optic is clean, examine it in a strong light and check for



137.191

Figure 7-21.–Cleaning a lens with a cotton swab.

smudges and streaks. Reclean if necessary. Sometimes a smudge is caused by fungus growth on the glass. This can be removed by rubbing the affected area with a soft cloth dipped in a paste of precipitated chalk or even cigarette ash. Rub just enough to remove the fungus. Do not remove more of the magnesium fluoride coating than necessary.

6. If you are satisfied that an element is perfectly clean, wrap it in lens tissue until you are ready to reassemble the instrument.

CEMENTING EQUIPMENT AND MATERIALS

When a lens requires recementing, set up all the equipment that you need in a clean, convenient area. In addition to the material for cleaning the lens, you will need a lens centering machine or two matched V-blocks, an electric hotplate with controlled heat, sheet asbestos to cover the hotplate, black paper, a rubber-tipped tool, tongs or brass tweezers for handling warm optics, a small glass bell jar or similar cover for the optical elements, and Canada balsam or other approved lens cement. Canada balsam is usually available in prepared form in metal tubes, through Navy supply channels.

Most lenses with a diameter over 2 1/2 inches are not cemented together; they are air-spaced. The elements of the lenses are made of glass with different rates of expansion which causes separation of the cement during temperature changes. Some large lenses are also ground with different curvatures on their mating surfaces, which makes joining by cement impossible.

The reasons for joining the elements of a lens by cement are:

1. Cementing keeps the elements optically aligned.

2. Cementing reduces the number of glass surfaces exposed to the air, which serves the same purpose as a film on optics–to reduce surface reflection and improve light transmission. Since the index of refraction of Canada balsam is about the same as that of crown glass, there is practically no reflection when two crown glass elements are cemented together, and very little reflection when a crown glass is cemented to flint glass.

3. Because a soft glass (hydroscopic) has special optical properties, a lens designer may sometimes desire to use it. This type of glass, however, is unstable and quickly deteriorates when used alone; but it can be used satisfactorily when cemented in place between two stable elements.

You will occasionally find a lens doublet (generally from a gunsight) that will not separate when heated. If the elements of a compound lens do not separate at a temperature of 300°F, they were probably cemented together with a thermosetting plastic, which a manufacturer sometimes uses for two reasons: (1) It resists temperature changes better than balsam, and (2) it speeds up lens production.

When you have reason to believe that lens elements have been secured together with a thermosetting plastic, check the lens under ultraviolet light for FLUORESCENCE. If the cement between the elements is a thermosetting type, there will be little or no fluorescence; if the cement is balsam, you will see a definite, hazy-white fluorescence. When in doubt about the cement used in lenses, consult your supervisor.

Separating Cemented Elements

Turn your hotplate on LOW, or set it for 300°F, and place a piece of 3/8-inch asbestos on top, over which you place a piece of black paper which serves as a temperature indicator. Put the lens on the paper and cover it with the bell jar or cardboard box. Watch the black paper for signs of scorching, which shows that the hotplate is too hot and more asbestos is needed, or the temperature should be reduced.

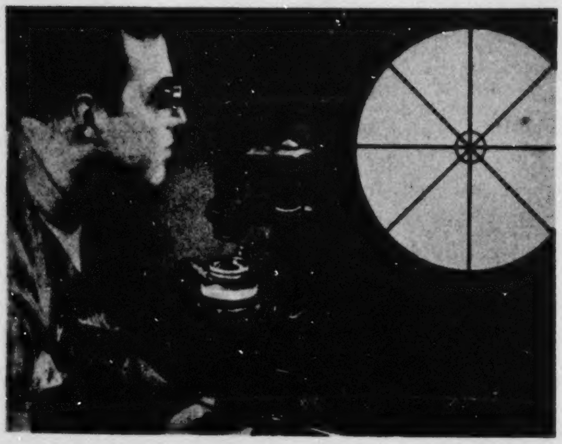
When the lens is hot enough (between 275° and 300°F), gently slide the elements of the lens apart with your rubber-tipped tool and allow them to cool slowly. When the temperature of the separated elements is approximately equal to that of the room, remove old balsam from them with alcohol, and then clean them thoroughly with acetone. If the elements do not separate at 300°F, the lens is probably cemented with thermosetting plastic. A single-edge razor blade inserted between the elements will usually separate them, and acetone will clean off the plastic cement.

Recementing

Put the clean lenses on the hotplate, with the surfaces to be cemented together facing upward. Inspect them for dust or dirt which may have fallen on them since they were cleaned, cover with the bell jar, and turn on the hotplate.

When the elements are hot enough, put a little balsam on the concave element, pick up the positive element with your tweezers, and join the two elements. Then use your rubber-tipped tool to work the top element over the lower one as much as necessary to squeeze out all air bubbles. The black paper on the hotplate makes air bubbles in the elements appear bright.

Use the lens-centering instrument (fig. 7-22) to center (align optical axes) the elements. This instrument consists of an upper astronomical telescope with a crossline and focusing eyepiece and a lower collimator telescope mounted on a common stand. The objective lens of one instrument faces the objective lens of the other instrument. The crossline mount of the collimator telescope moves in a threaded mount, which enables you to bring the image of its crossline into focus with the image of the astronomical telescope, regardless of the size lens mounted between the telescopes. A lens chuck on the lower telescope grips the element being centered. The entire lower telescope can be freely rotated to check for eccentricity. To save time when centering a cemented doublet, you should place the lens in the centering instrument and focus the two telescopes prior to separating the lens.



137.192

Figure 7-22.–Lens-centering instrument.

Heat the chuck jaws with a small torch or a hot piece of metal and then transfer the hot lens to the chuck. NOTE: Cold chuck jaws may crack one or both elements of the lens. Mount the hot, freshly cemented lens in the warm chuck, which grips ONLY the negative elements of the lens.

Sight through the eyepiece while you rotate the lower telescope, and observe the eccentric movement of the lower crossline. Move the upper element of the cemented lens over the lower one, as necessary, to remove all eccentricity as the lower telescope is rotated.

The insert in figure 7-22 shows the crossline pattern of the two telescopes. The plain diagonal crossline is the image from the lower telescope. This crossline must stay within the small circle as the lower telescope is rotated; however, perfect coincidence is more desirable.

Allow the lens to cool for a few minutes in the machine and recheck the alignment, remove the asbestos sheet from the hotplate, and place the lens on the asbestos sheet. Then cover the lens with the bell jar (or box) and allow the lens adequate time for cooling. When cool, remove the bell jar and scrape excess balsam from the edge of the lens with a razor blade, after which the lens is ready for final cleaning and inspection.

NOTE: If you do not have a lens-centering machine, use V-blocks in the following manner to align the optical axes of a compound lens: Heat the V-blocks on the hotplate while you are cementing the lens elements. When you have the elements joined, slide the V-blocks against the edges of the lens from opposite directions. Then turn off the hotplate, cover the lens and V-blocks, and allow the combination to cool simultaneously. NOTE: Elements whose diameters differ cannot be cemented in this manner.

CHAPTER 8

MAINTENANCE PROCEDURES—PART II

REASSEMBLY

Now that you have done the essential repairs to instrument parts, the necessary refinishing, the required cementing of optical elements, and everything is perfectly clean, you are ready to reassemble the instrument.

If you have accomplished your repair and overhaul well, reassembly will be smooth and easy. Unless you know the instrument on which you are working very well, follow a reassembly sheet. Because reassembly is different for each instrument, no set procedure can be given in this manual. The reassembly tips presented in the next few pages, however, will be helpful.

REPLACING LENSES

Before mounting lenses in their cells or mounts, you must be sure that all dirt and foreign matter has been cleaned from the cell. If the interior of the cell is particularly long or hard to clean, you can remove most particles by this simple method: First, cover the open ends of the cell with masking tape. Then with the cell held in an upright position, tap on the exterior with a small 2- or 3-ounce fiber mallet. The dirt will loosen from the cell and drop to the end of the cell where it will stick to the tape. You can use this procedure also on large body tubes and castings.

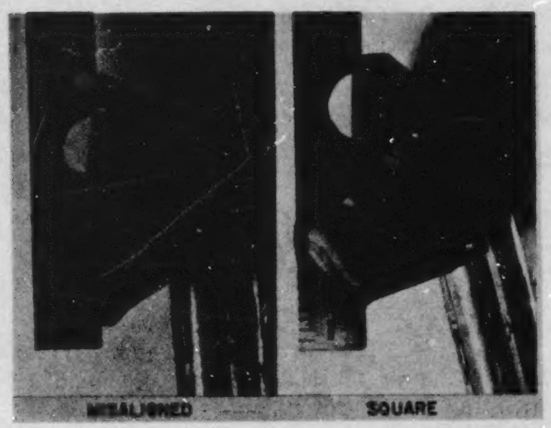
All of your clean optics should have been wrapped in lens tissue. When you unwrap lenses, prior to replacement in their mounts, you will usually find a few pieces of lint from the lens tissue adhering to the lenses. Blow this lint off with an air bulb before replacing the lens in its mount. If you are replacing an objective lens or eyelens, make sure the gasket is properly in position in the mount to maintain the seal.

To avoid putting fingerprints on the edge of a lens, hold the lens on its retainer ring or use a lens chuck as you insert the lens in the mount. Be sure the lens is facing the proper direction, or you will have to disassemble the instrument later. The lens must be fully seated, without being cocked, and the retainer ring must be snugly tightened. If the retainer is loose, collimation will be impossible, and the seal may not hold. If the retainer is too tight, there is the risk of distortion or cracking.

REPLACING PRISMS

After you assemble all lenses in their cells and mounts, assemble the prism clusters, or prism mounts (if any). Secure the prisms in their mounts by straps and/or collars, which must fit snugly enough to hold the prisms but not so tight that they may cause strain. A collar should fit over a prism with a slight press. If the fit is too tight, strain and breakage usually result; if the fit is too loose, the prism may shift position and throw the instrument out of adjustment.

When you assemble a porro prism cluster, check the assembly for lean before you put it into the instrument. In a prism erecting system, lean results when the prisms are not oriented exactly 90° to each other. Figure 8-1 shows how



137.558
Figure 8-1.—Porro prism cluster squaring.

lean appears. Any deviation from a perfect 90° orientation will result in twice the amount of deviation as you view a target through the cluster.

Various adjustments are provided on prism plates to remove lean. Some have collars which fit the prism tightly. These collars have four oversize holes for the securing screws, which allow slight movement in any direction. Others use eccentric washers, or tapered washers which bear against the edges of the prism.

When you assemble porro prism clusters, place the prism in the center of the milled out depression in the prism plate, tighten the strap over the top of the prism, then snug the adjusting screws. Be careful not to touch the polished surfaces at any time while adjusting a prism cluster.

To remove lean from a prism cluster, look through the cluster with one eye and at a prominent vertical or horizontal reference (such as a stanchion, door frame, or graph paper) with the other. By shifting one prism slightly, you can align the inverted-reverted reference you see through the cluster with the normal reference you see with your other eye. This procedure will require some practice since you must train your eyes to see two different objects at the same time. If adjusting one prism does not remove lean, you may have to adjust the other prism or reverse a prism on the prism plate. After lean is removed, tighten the prism strap and check to be sure the adjusting screws are tight.

During assembly and adjustment of a prism cluster, it is easy to cock a prism. You can remove lean with a cocked prism, but the prism may chip, deviating the line of sight through the cluster too much to allow collimation.

ASSEMBLING MECHANICAL PARTS

As you assemble parts in an instrument, be sure to match all assembly marks; otherwise, you will need to disassemble the instrument, make corrections, and reassemble it.

Check each part as you reassemble it for fragments of foreign matter clinging to it. Each part MUST BE IMMACULATELY CLEAN before you assemble it in the instrument. Keep openings to the interior of the instrument closed with masking tape, and remove it only when you must make additional installations. Follow this procedure as you reassemble each part, until you make the final closure.

As you replace components and parts in an instrument, try to work from the top downward to prevent unnecessary work over an optical element, and perhaps damage to it.

Do not force a part into place in an optical instrument; use a light press with your fingers. If a part must be fitted in position by force it must be done in accordance with specifications. If there is a bind, determine the cause.

You can make some adjustment to parts as you assemble them in an instrument. Whenever possible, these adjustments should be made during collimation. In some instances an adjustment is impossible after reassembly because of inaccessibility of parts.

Threads on retaining rings, lens mounts, caps, screws, and setscrews are extremely fine and can be cross-threaded easily. When you assemble them, turn in a counterclockwise direction until the threads snap into place; then turn clockwise.

Lubricate components, as necessary, with approved lubricants during assembly. Use lubricants sparingly–you do not want to contaminate an otherwise clean optic with a smudge of grease. Use an antiseize compound on external screw threads and threaded portions of body tubes. Silicone grease is an excellent antiseize. It will not melt or run and it will prevent corrosion. Do NOT use any grease on a lens retainer ring.

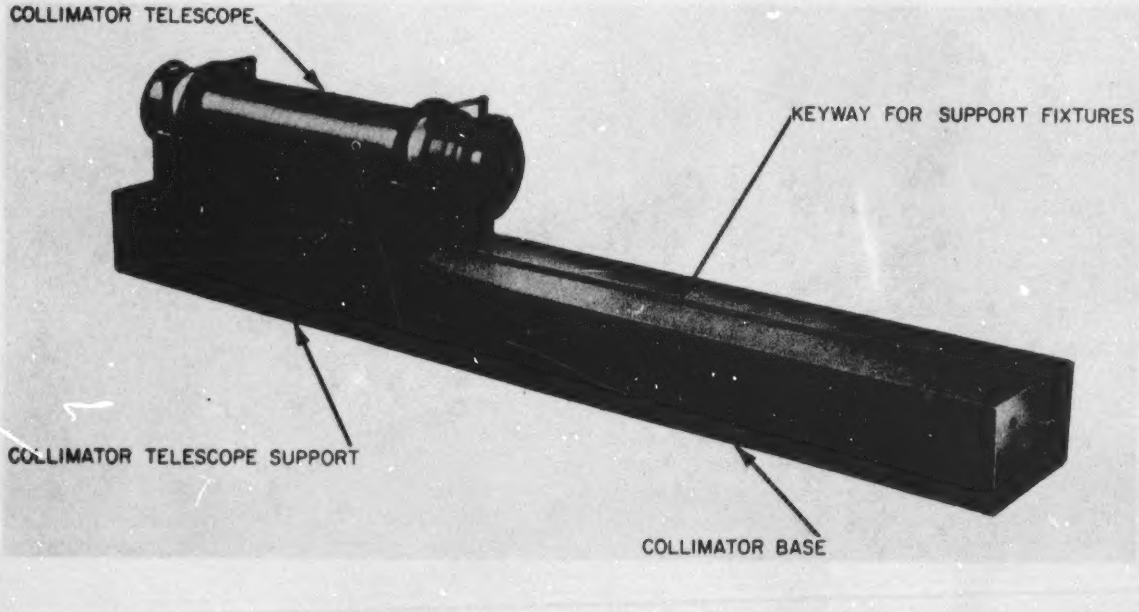
COLLIMATION

One of the final steps in overhaul and repair of an optical instrument is collimation, which is the alignment of the optical axis of the instrument to its mechanical axis. In simpler terms, collimation is directing all the lenses in an optical system in such manner that they coincide with each other in a straight line and parallel to the mechanical axes of the bearing surfaces (telescope's mounting pads, for example). Collimation also consists of adjusting the focus of individual lenses and assemblies so that the target (and crossline if included) will be in perfect focus.

COLLIMATION EQUIPMENT

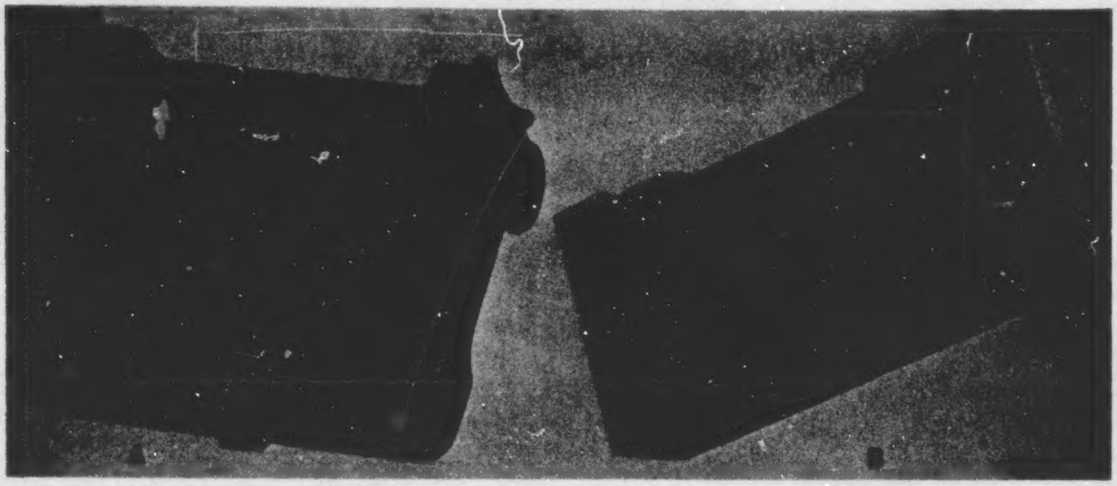
Collimators are precision instruments (with both optical and mechanical elements) which provide an infinity target suitable for use in aligning and adjusting the optical and mechanical components of optical instruments so that they will perform accurately.

Although collimators may vary in design and/or construction, they all operate on the same principle. Figure 8-2 shows the Mk 4 Mod 0 collimator used on small telescopes, gunsights, and navigational instruments. It has a steel base several feet long with a precision, flat bearing surface machined on its entire top. A keyway is



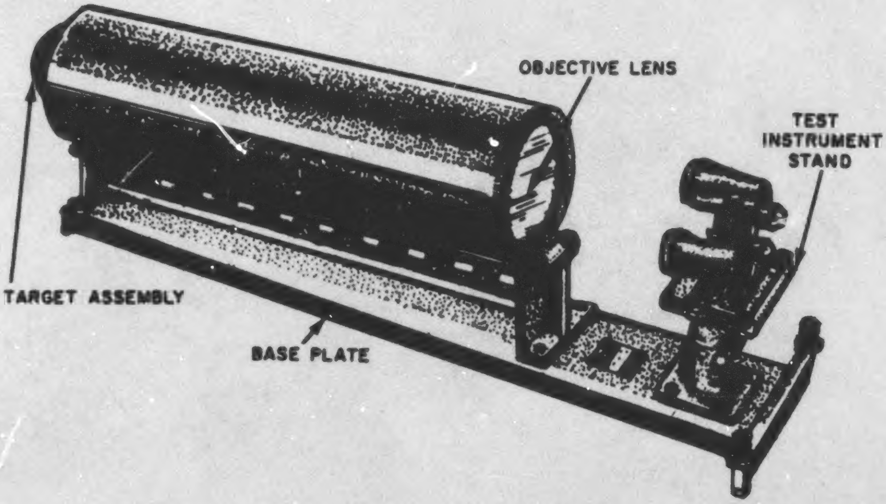
137.200

Figure 8-2.–Collimator, Mk 4 Mod 0.



137.202

Figure 8-3.—Auxiliary support fixtures.



148.232

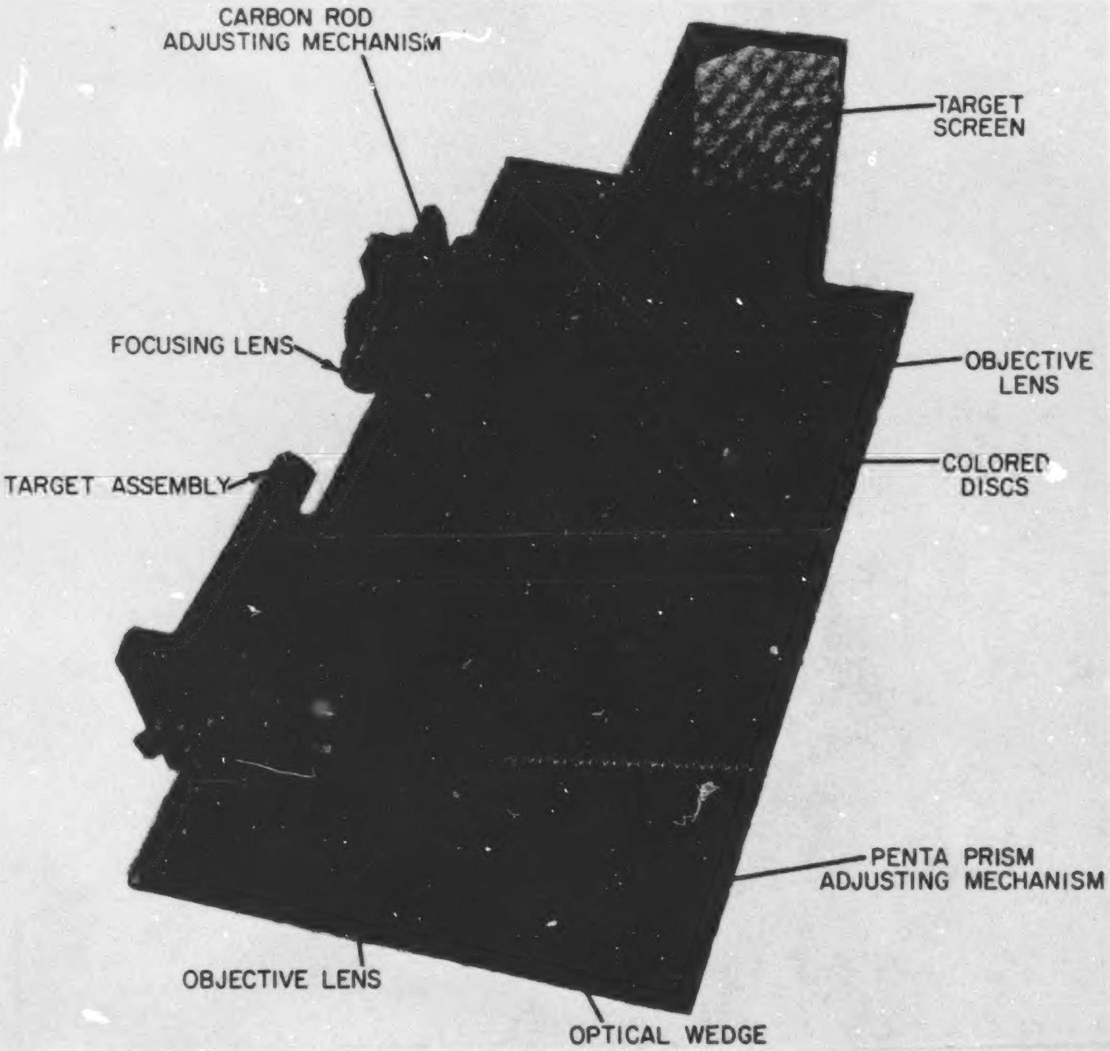
Figure 8-4.—Mk 5 binocular collimator.

cut down the center of the bearing surface, as shown, for aligning support fixtures.

The collimator telescope is secured to the bearing surface on a V-block support with two square keys holding the collimator telescope support in alignment with the base. The collimator telescope can be rotated by hand to change the orientation of the crossline.

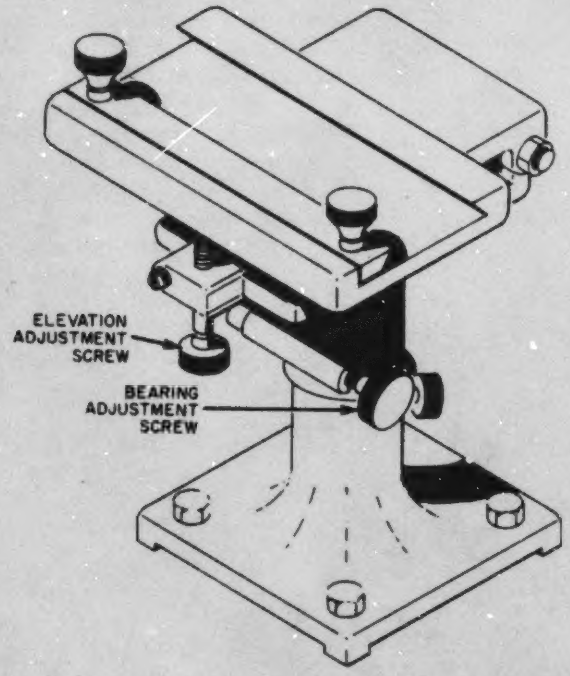
Figure 8-3 shows two auxiliary support fixtures which are used with the Mk 4 Mod 0 collimator. The fixtures differ because of the physical configurations of the telescopes for which they are designed, yet both fixtures fit the Mk 4 Mod 0 collimator.

Figures 8-4 and 8-5 show two entirely different collimators used to align hand-held binoculars. The mounting stand shown in figure



148.240

Figure 8-5.–Mk 13 binocular collimator.

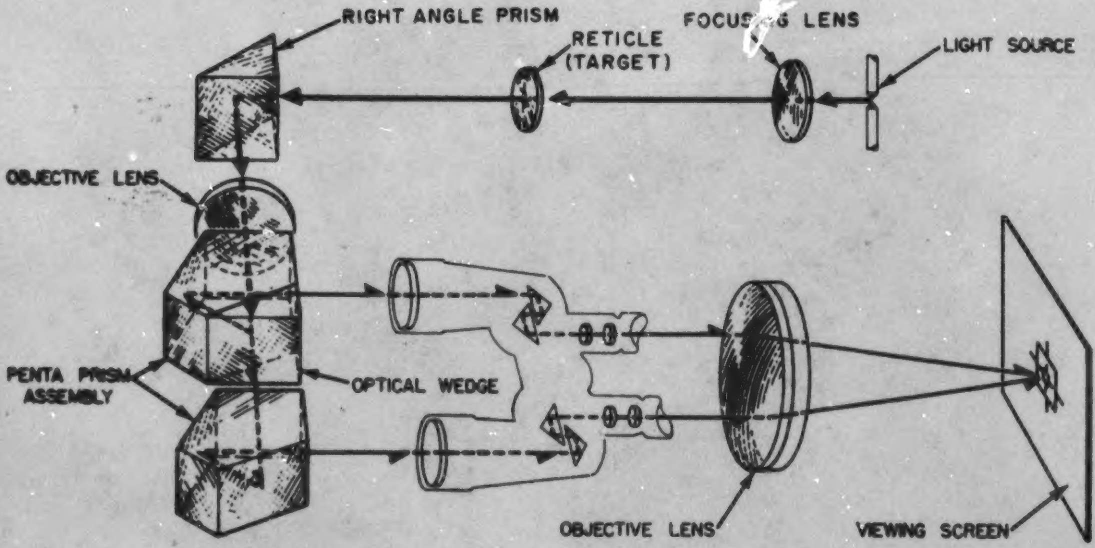


148.234
Figure 8-6.—Test instrument mounting stand.

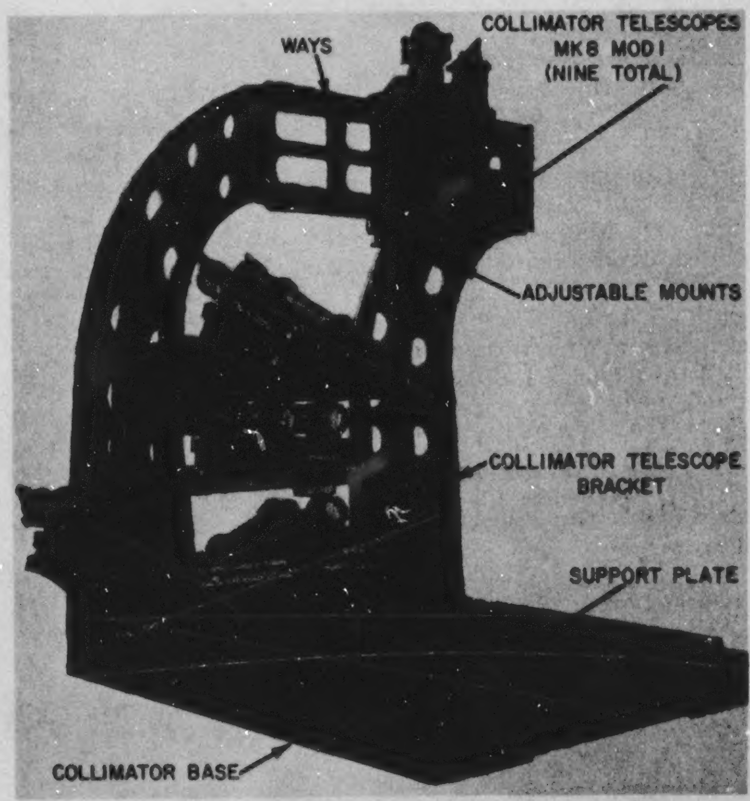
8-6 fits the Mk 5 collimator which it adapts to binoculars, sextants, and stadimeters. The Mk 13 collimator will accept only binoculars. The optical system of the Mk 13 collimator is shown in figure 8-7.

Large tilting prism gunsights are collimated on the Mk 9 collimator (fig. 8-8). This instrument is rather large and bulky, since it is designed to accept large gunsights, but it is a very precision instrument. The support plate, which can be rotated, has numerous tapped holes which are used to secure a variety of telescope supports that hold all types of gunsights. Notice the double bank of collimator telescopes. This feature allows the collimation of both single eyepiece and binocular type gunsights. These collimator telescopes are mounted at -25°, 0°, +25°, and +90° so that gunsights can be adjusted through the full range of elevation and depression.

The collimator telescope used on the Mk 9 collimator is shown in figure 8-9. It is normally used with the mirror (to reflect light and illuminate the crossline). For special purposes, such as establishing a true line of sight between

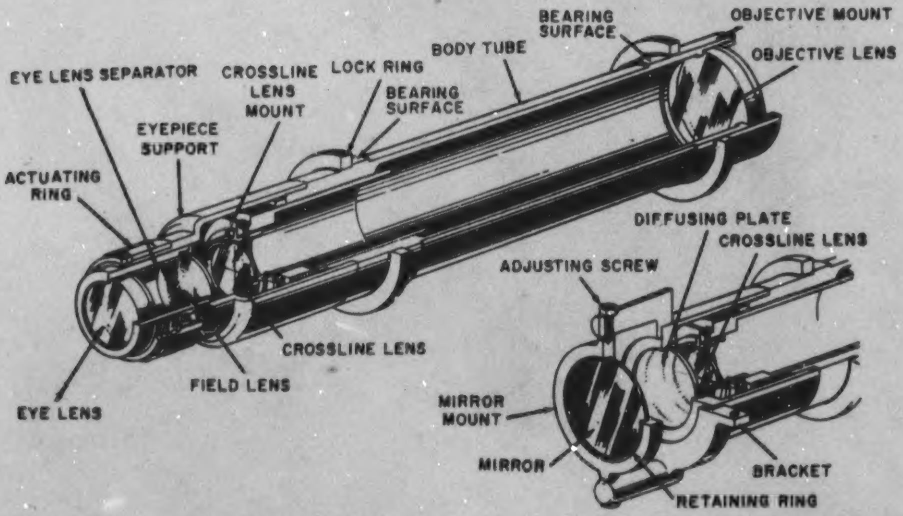


148.239
Figure 8-7.—Mk 13 binocular collimator—operational schematic of optical system.



148.245

Figure 8-8.—Collimator Mk 9.



148.272

Figure 8-9.—Collimator telescope Mk 8 Mod 1 with auxiliary eyepiece, mirror mount, and diffusing plate—cutaway.

two collimator telescopes, it is available with an eyepiece.

For further information on collimators, consult OP 1417, *Collimators for Optical Instruments*.

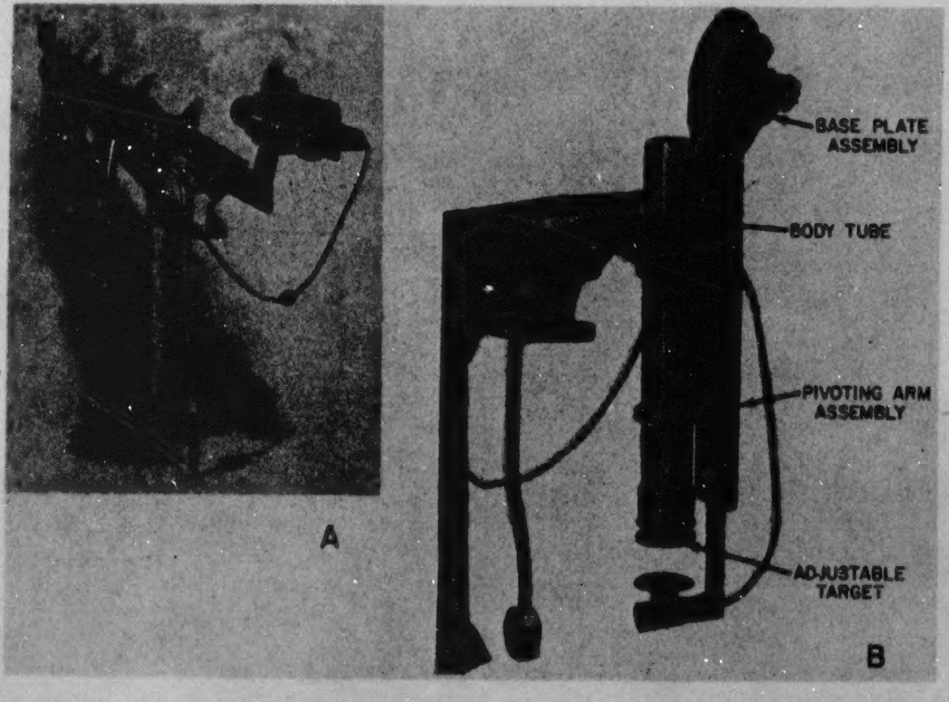
Collimation of submarine periscopes presents two unique problems–the length of the instruments and the need for an adjustable target. Figure 8-10A shows the collimator mounted in the horizontal position on the periscope rail. Part B of figure 8-10 shows a closeup of the collimator. The periscope rail shown is about 45 feet long. The sliding V-blocks support the periscope to prevent sagging of the tube.

Of all the tools you will use as an Opticalman, the auxiliary telescope is the most common for adjusting most of the instruments for which you are responsible.

Auxiliary Telescope

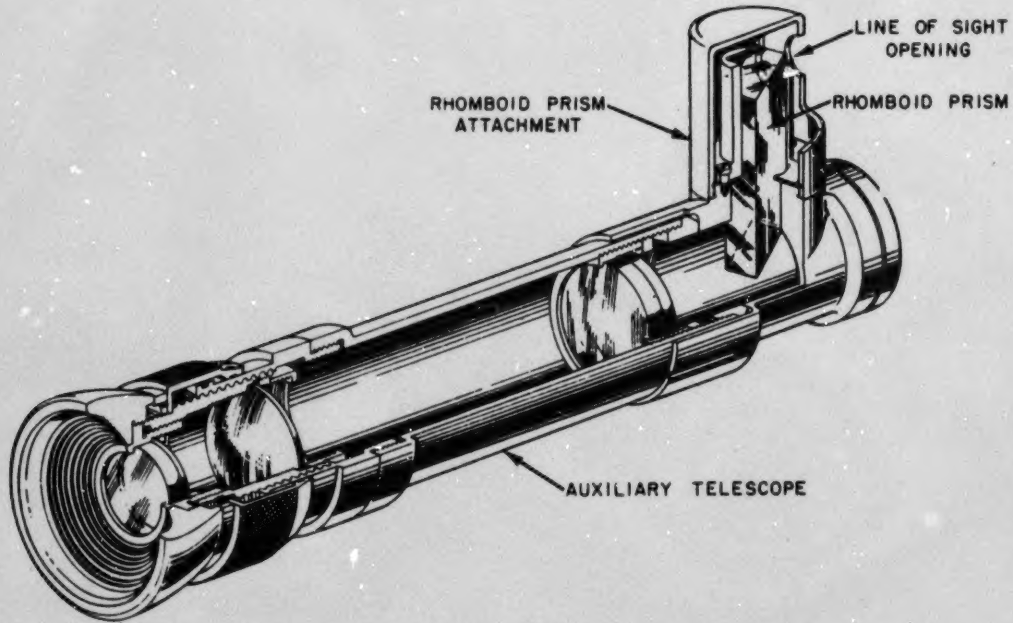
Figure 8-11 illustrates the auxiliary telescope with a rhomboid prism attachment. With this attachment you can look through an instrument and see a magnified image of a collimator, while at the same time you can see a reduced image of the collimator superimposed on the main line of sight. The rhomboid prism attachment slips over the objective end of the auxiliary telescope when needed.

The auxiliary telescope is a three-power astronomical telescope (inverted reverted image) with a focusing Kellner eyepiece. Its main purpose is to correct for, and neutralize, inherent eye defects you may have and to slightly magnify so that you can adjust an optical system more accurately.



148.253(254)

Figure 8-10.–Periscope collimator and rail.



148.261

Figure 8-11.–Auxiliary telescope Mk 1 with rhomboid prism attachment–cutaway.

To determine the dioptric setting of your eyes, focus the auxiliary telescope from plus to minus on an infinity target, or on a collimator telescope crossline, until the image is sharply defined. For best results, take five readings and use the reading which appears most during the readings. Remember to keep your eyes relaxed while focusing.

After you get this dioptric setting, do NOT change the focus until you check your setting again to adjust for eye fatigue or strain.

You can use an auxiliary telescope for the following collimation operations:

1. To set focusing eyepieces to the NORMAL or ZERO diopter setting.
2. To set fixed-type eyepieces to their required diopter setting.
3. To check for and aid in removing parallax in an instrument.

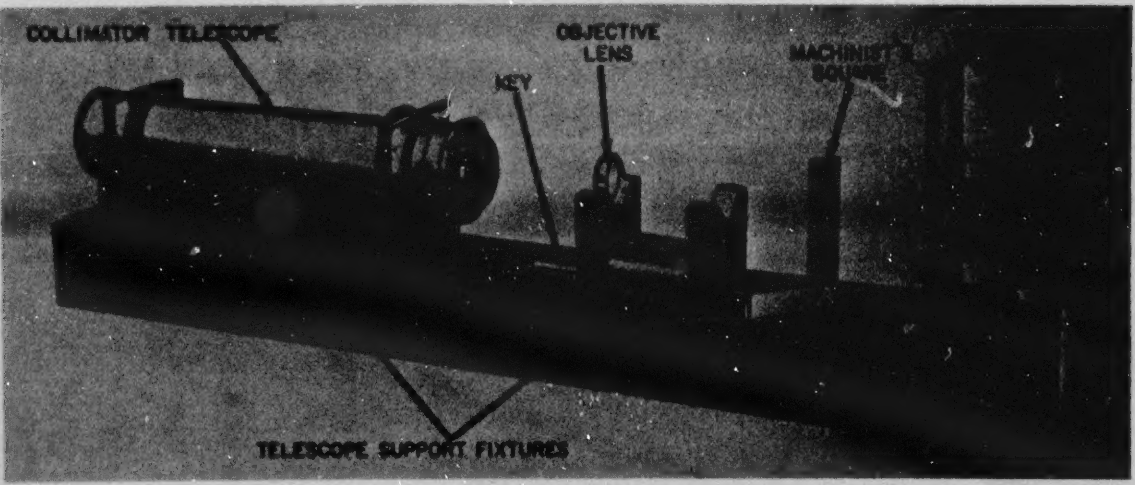
The auxiliary telescope increases the accuracy of these adjustments by a factor of three. If you are adjusting a six-power instrument with an auxiliary, the final magnification of the collimator image will be 18X. (3X auxiliary multiplied by 6X telescope).

NOTE: Always use an auxiliary telescope during collimation procedures.

COLLIMATOR ADJUSTMENT

Alignment of a collimator serves two purposes. It establishes parallelism between the base and the optical line of sight, and it sets up the collimator to correspond with alignment specifications for the instrument being collimated.

Figure 8-12 shows the Mk 4 Mod 0 collimator and the equipment necessary to square the collimator crossline. Light leaving the collimator is parallel. An auxiliary objective with a 10- to 15-inch focal length is placed near the



137.206

Figure 8-12.—Squaring collimator crossline.

collimator. An adjustable auxiliary eyepiece is positioned behind the auxiliary objective so that you can see a sharp image of the collimator crossline. Now place a machinist's square in the image plane of the auxiliary objective. You should see the collimator crossline and the edge of the machinist's square in sharp focus. Simply rotate the collimator telescope to align the vertical line with the edge of the square. No further alignment is necessary on the Mk 4 collimator.

Some collimators must be aligned with special, single-purpose equipment. Others can be aligned to accommodate a variety of different telescopes by using a checking telescope.

The Mk 7 checking telescope (fig. 8-13) has a graduated dial and vernier index so that you can set the telescope at any angle of elevation or depression. The eyepiece prism is fully rotational so that you can comfortably view the target from any position.

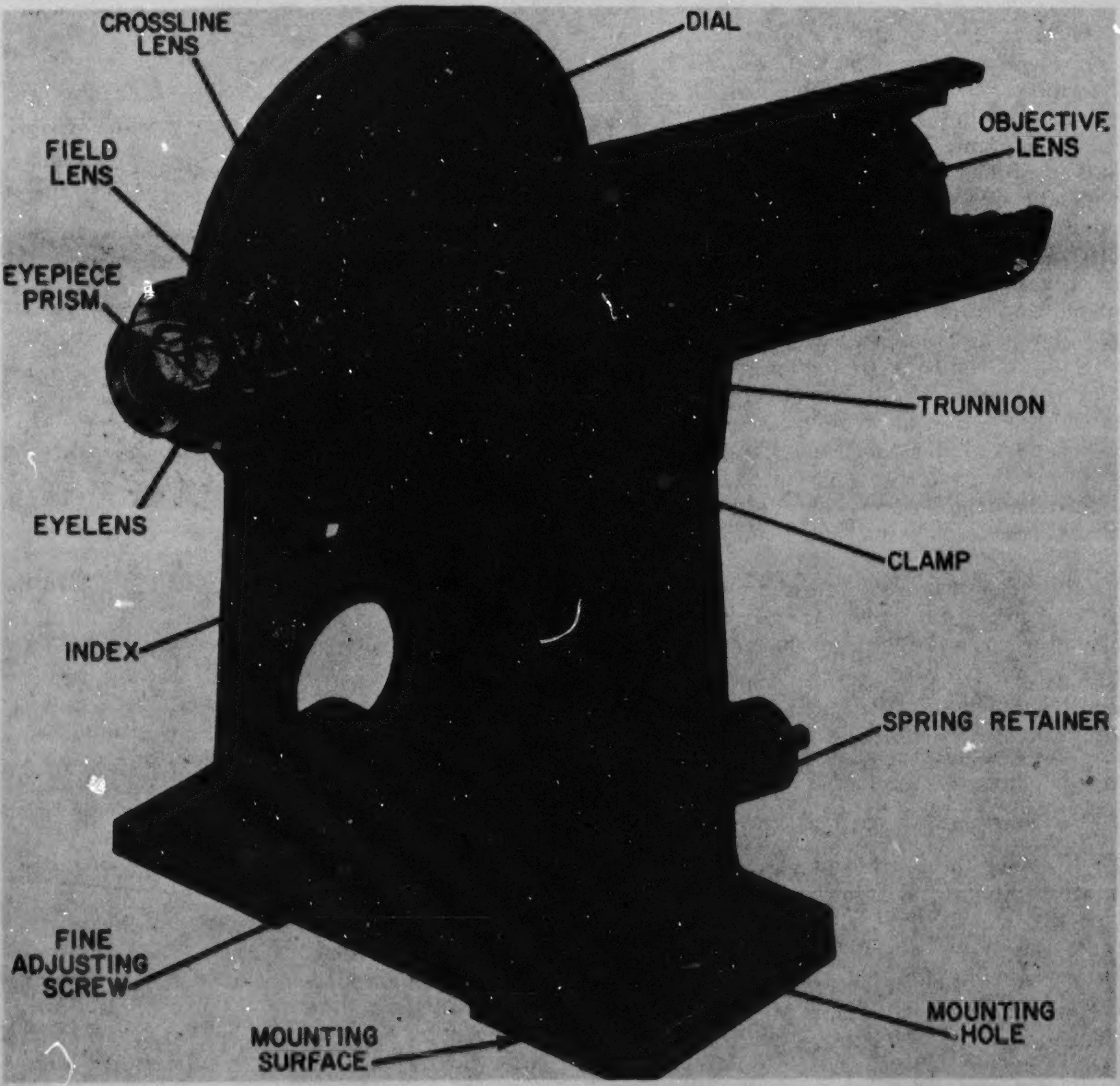
To align a collimator using the Mk 7 checking telescope, mount the checking telescope on the appropriate support fixture, set the dial to the specified elevation, and adjust the collimator telescope to align with the checking telescope. (The checking telescope is the primary reference.)

Adjust the collimator immediately prior to collimating an optical instrument. In some cases, you will need to make readjustment during collimation because temperature changes will affect alignment of the collimator.

COLLIMATION PROCEDURES

Collimation procedures vary for different types of optical instruments. While one type of instrument may require several hours of complicated adjustment, another can be completed in a few minutes. You will encounter situations when making one adjustment will change a previous adjustment, and some instruments will need to have subassemblies collimated before you can collimate the complete telescope. In tilting prism gunsights, you may have to shim or scrape mounting surfaces to obtain proper tracking of the line of sight.

To obtain detailed procedures for collimation of any particular instrument you must consult a job sheet or technical manual.



137.203

Figure 8-13.—Mk 7 checking telescope.

The following general information will apply to most optical instruments, in the order in which it should be performed.

1. Collimate the collimator.
2. Remove parallax.
3. Square and superimpose the crossline.
4. Set zero diopters.

Removal of Parallax

To check for parallax in an instrument, place an auxiliary telescope on the eyepiece of the instrument, sight through the auxiliary telescope, and focus the eyepiece of the instrument until the image of the collimator crossline, or the crossline of the instrument (whichever comes into view first), is sharply defined. If parallax is present, one of the two crosslines will come into focus first; if there is no parallax, both crosslines will be in focus at the same time. To determine the amount of parallax, focus the eyepiece of the instrument in until the first crossline is sharply defined, and observe the diopter reading to which the index marker points. Continue to focus until the other crossline is sharply defined and observe the point of the index mark on the diopter scale. Also note the number of diopters between the position of clarity of the first crossline and the point of clarity of the second crossline. If the instrument's crossline, for example, came into focus at +2 diopters on the diopter scale and the collimator's crossline came into focus at -3 diopters on the diopter scale, the total amount of parallax is 5 diopters.

If the instrument's crossline comes into focus before the collimator's crossline, the objective lens is too far from the crossline. If the collimator's crossline comes into focus before the instrument's crossline, the objective lens is too close to the crossline.

The problem now is to place the instrument's crossline in the focal plane of the objective lens, in one of two ways:

1. Move the instrument's crossline forward or aft axially until it is in the focal plane of the objective lens.
2. Move the objective lens until its focal plane is in the same plane as the instrument's crossline. This method is preferred for removing parallax. The objective lens is usually mounted in a threaded mount which can be moved axially along the interior of the instrument. When the objective lens mount is moved any amount, the image of the collimator's crossline moves in the same direction in the same amount as the objective lens.

In some instruments spacers or separators are placed in front of, and behind, the objective lens mount (not threaded externally) to allow for elimination of parallax by trial and error. There is NO tolerance for parallax in any optical instrument.

Continue adjusting the instrument until both crosslines are in perfect focus at the same time.

Squaring and Superimposing the Crossline

To square the instrument crossline to the collimator crossline:

1. Loosen the crossline retainer ring.
2. Rotate the crossline with a rubber tipped tool.
3. When the crosslines are aligned, tighten the retainer.

The crossline may turn past the desired position. This procedure can sometimes be quite frustrating, but it must be done carefully and accurately. As you make adjustments to the crossline, it could become smudged or dirty. You will have to remove and clean the crossline again. THE CROSSLINE MUST BE ABSOLUTELY CLEAN.

Once the instrument crossline is perfectly squared, and clean, superimpose it on the collimator crossline. Instruments are designed in a variety of ways to accomplish this adjustment. One design is to shift the prism erecting system (which may cause lean), another is to adjust the crossline lens mount (screw adjusting mount). The most common design is the use of an eccentric objective mount. With proper manipulation of the eccentric rings, you can vary the line of sight of the instrument to give perfect alignment.

Eccentric rings are locked in position with setscrews, lock rings, or both. When you lock the eccentrics, your adjustment may be thrown off slightly, so be sure to check it. If full throw of the objective is not enough to superimpose the two crosslines, you may need to shift prisms, recheck for lean, and try again. When you have difficulty superimposing the collimator and instrument crosslines, try the following procedures:

1. Check the collimator alignment.
2. Check the instrument mounting surfaces.
3. Disassemble the instrument and look for cocked lenses, prisms, or mounts.

After you have squared and superimposed the crosslines, recheck for parallax.

Setting Zero Diopters

Instruments with a focusing eyepiece are set to zero diopters with an auxiliary telescope, so that anyone using the instrument can automatically set the eyepiece at his or her own diopter setting without wasting any time focusing. During reassembly of spiral keyway eyepieces, you will set the index mark at mechanical midthrow (zero diopter position) and adjust lenses during collimation to establish a perfect focus at zero diopters.

To set optical zero diopters, use an auxiliary telescope set to your eye correction, and focus the instrument being tested until the collimator is in sharp focus. NOTE: Always focus from the plus side (out) to the minus side (in).

When you removed parallax, the instrument crossline and collimator target were in focus at the same time. This common focus may not correspond with the zero mark on the instrument eyepiece. For instance, if both crosslines are in focus at -2 diopters, the final image plane is in too far. On the other hand, if both crosslines are in focus at +1 diopter, the final image plane is out too far.

To establish a perfect zero diopter focus in a two erector telescope, simply move the rear erector in the same direction you want the image plane to move. For instruments with a single erector, move the erector in the opposite direction you want the image to move (remember the optical theory discussed in earlier chapters).

In instruments without a crossline, using a prism erecting system, the focal length of the objective lens or the axial positioning of the objective lens will determine the zero diopter setting.

The collimation procedures just discussed generally cover fixed prism gunsights and straight-line telescopes without crosslines. Instruments with elevation and deflection prisms or mirrors must be checked against a properly adjusted collimator for true horizontal and vertical tracking as well as mechanical backlash.

Modern gunsights are precision manufactured to fine tolerances to keep possible misalignment to a minimum. However, damage or incorrect reassembly can cause problems. The technical manual for each type of instrument fully covers the correct overhaul and collimation procedure and lists the tolerances for errors in elevation, deflection, and backlash. As a rule, the line of sight can vary no more than 1 or 2 minutes of arc from the desired plan of movement, and backlash is held to 30 seconds, or less. Proper adjustments include shimming, scraping, or replacing machined spacers, as specified in the technical manual.

SEALING, DRYING AND CHARGING

After you collimate an optical instrument, the last step in overhaul is to seal the instrument, remove any moisture present, and charge the instrument with a dry, inert gas when appropriate. Much of the sealing process is usually accomplished during reassembly, except for areas needed for access during collimation.

Optical instruments are designated as (1) moisture-tight, (2) gas-tight, or (3) pressure-tight. Methods used for sealing, drying, and charging vary with the type of instrument being overhauled.

MOISTURE-TIGHT

Hand-held optical instruments, or those not permanently mounted on a ship's weather deck, are classified as moisture-tight. They have focusing type eyepieces and are sealed against the entrance of moisture by gaskets, sealing compound, and grease (in the eyepiece focusing mechanism). These instruments are sealed in the optical shop at normal atmospheric pressure. They will withstand mist or light rain, but cannot be submerged in water.

GAS-TIGHT

Instruments which are permanently exposed to the weather must be sealed with a positive gas pressure of 2 to 5 psi. They have fixed focus or internal focusing eyepieces, and all joints and optics are sealed with gaskets. Since these instruments use control shafts passing through the body casting, the shafts are sealed with packing. The packing holds internal pressure and will allow the control shafts to be rotated.

PRESSURE-TIGHT

Instruments which must withstand high external water (hydrostatic) pressure for extended periods of time are sealed with O-rings, packing, and gaskets. They will also be charged with inert gas at a pressure of 5 to 7 1/2 psi. The primary purpose of sealing, drying, and charging an optical instrument with gas is to prevent moisture from getting into the instrument and condensing on parts, thereby rendering them useless.

A gas-tight instrument may be charged with dry nitrogen or helium. A pressure-tight instrument should be charged with dry nitrogen ONLY. Dry nitrogen and dry helium are used to charge instruments because they are inert gases; that is, they do not react chemically to cause or support corrosion.

Gas used to charge optical instruments is normally not completely free of moisture and foreign matter. You must clean the gas before you use it. Force the gas through an optical instrument dryer, which is actually a filter containing a quantity of silica gel to absorb moisture from the gas as it passes through. The silica gel used in instrument dryers is impregnated with cobalt chloride, which serves as a moisture indicator. When the silica gel is completely dry, it is deep blue. When the silica gel contains moisture, it is lavender; when it contains 50% moisture, it is pale pink. At a saturation of almost 100% with moisture, silica gel is decidedly pink.

You can check the color of the silica gel through a window on the side of the cylinder. When it changes to pink, remove it from the cylinder, place it in a container, and bake it in an oven at a temperature of 300° to 350°F for a minimum of 4 hours, after which its color should be a deep blue. If silica gel turns brown, replace it. While the silica gel is being baked, clean the inside of the dryer and the filters.

The use of nitrogen and helium for pressure-testing gas-tight and pressure-tight instruments, as prescribed in the various instrument manuals, requires you to be familiar with safe handling practices concerning high-pressure gases and storage cylinders.

SAFETY PROCEDURES FOR HANDLING CYLINDERS

You must strictly observe the following rules for storage, handling, and use of cylinders.

- Avoid abusing cylinders. They are carefully checked at the charging plant for safe condition. Abuse may easily render them unsafe.

Be sure the cylinder contains the proper gas, and do NOT tamper with the identifying code numbers and markings on the cylinders.

Store cylinders in an approved vertical storage rack where they cannot be knocked over or damaged by passing or falling objects. If a cylinder falls over, it may crack and explode, since a full cylinder contains pressure of 1800 pounds per square inch. If the cylinder valve is broken, the cylinder will take off like a rocket. Cylinders should be kept away from stoves, radiators, furnaces and other heat sources.

- While moving cylinders, prevent them from being knocked over or from falling. Use a suitable handcart with retaining devices.

- Keep cylinders from being knocked over while in use. Use a rack to hold the cylinder in an upright position.

- Use full cylinders in the order in which they are received from the charging plant.

- Never allow cylinders to come in contact with live wires and ground wires of electrical equipment.

- Always close the cylinder valve when work is finished. Always close valves of empty cylinders while in storage before returning them to the charging plant.

- Return empty cylinders promptly.

NEVER use a cylinder that contains less than 400 pounds of pressure. Gas cylinders contain impurities which could enter and contaminate an instrument if the cylinder is emptied.

CHARGING PROCEDURES

Figure 8-14 shows a typical setup for purging, pressure-testing, and charging an optical instrument. In this illustration, a rangefinder is being charged with helium, but the same equipment is also used with nitrogen and on other instruments.

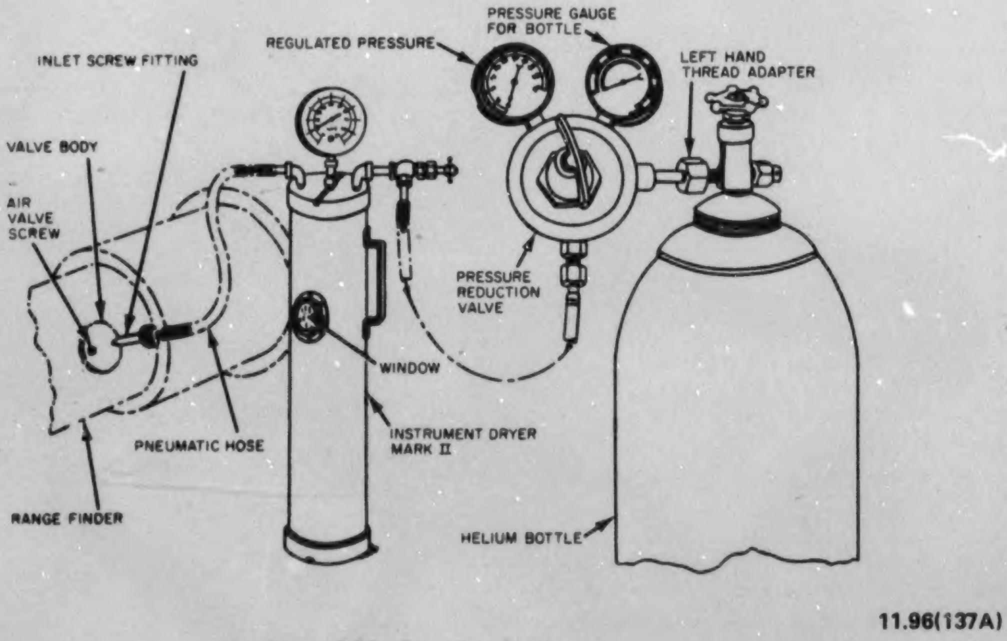
Plastic hose must be used from the dryer to the instrument. Rubber hoses are not clean. They tend to "shed" foreign matter. It is also advisable to use a plastic hose from the regulator to the filter.

The following procedure shall be followed. It is prescribed to protect you and the equipment.

- Set a cylinder of nitrogen in a rack in a vertical position. Observe the safety procedures for handling cylinders. Make sure the cylinder contains nitrogen.

- With the cylinder firmly in the rack, unscrew the valve protection cap from the top of the cylinder.

- Open the cylinder valve one-quarter turn and then close it immediately. (Do NOT stand in front of the outlet pipe; stand behind it.) This procedure will clear the valve and the outlet pipe of dust and dirt that may have been accumulated during storage and shipment. Otherwise, such dirt might be blown into the regulator and damage it.



11.96(137A)

Figure 8-14.—Setup for charging.

WARNING

DO NOT USE A WRENCH ON THE CYLINDER VALVE. IT SHOULD OPEN TO HAND PRESSURE. IF IT WILL NOT YIELD TO HAND PRESSURE, REPLACE THE VALVE PROTECTION CAP AND RETURN THE CYLINDER TO THE CHARGING PLANT WITH AN EXPLANATION ATTACHED.

- Assemble the pressure-reducing regulator to the cylinder. Tighten the union-joint nut securely.

- Turn the pressure-adjusting control screw of the regulator counterclockwise (to the left) until it is loose to protect the regulator and its gages from possible damage when the cylinder is opened.

- Stand to one side of the front of the regulator and open the cylinder valve sightly. If the cylinder is opened quickly, the sudden rush of gas might damage the regulator. Open the valve only enough to make the cylinder pressure gage indicate a slow rise in pressure. When the needle of the gage stops, open the cylinder valve all the way.

WARNING

IF THERE IS A LEAK BETWEEN THE CYLINDER AND THE REGULATOR, CLOSE THE CYLINDER VALVE BEFORE TIGHTENING THE COUPLING OR BEFORE DOING ANYTHING ELSE.

- Connect the hoses and the instrument dryer together as in figure 8-14. Make sure the hose from the regulator is attached to the inlet side of the dryer.

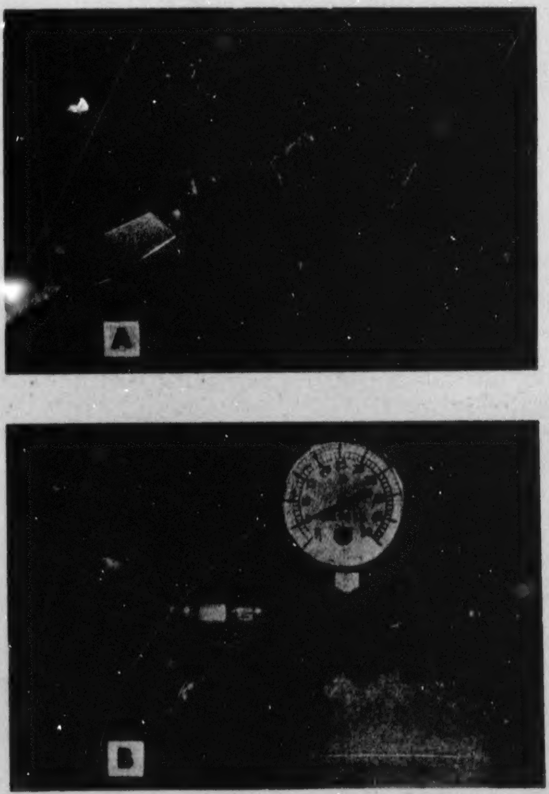
- Turn the pressure adjusting control screw of the regulator clockwise until the regulated pressure gage reads 5 pounds to blow out the filter and the lines.

- Reduce the pressure again. The system is now ready for use.

Testing for Leaks

When an instrument is to be tested for leaks the general procedure is:

- Connect the hose from the outlet side of the dryer to the charging valve screw fitting (the small screw) on the optical instrument (fig. 8-15A).



137.207

Figure 8-15.—Attaching hose to instrument charging valve.

- Open the gas inlet screw (large screw) on the valve.

- Tighten the gas outlet screw on the opposite end of the optical instrument.

- Turn on the nitrogen supply until the pressure gage on the instrument dryer reads approximately 5 pounds per square inch (fig. 8-15B).

- While you maintain this pressure, brush a soapsuds solution around all fittings, gaskets, screws, the objective window, and the rear eyelens to check for leaks. See figure 8-16.

- If you find leaks, mark them with a soft lead pencil, white crayon, or chalk; turn off the air supply; disconnect the hose from the instrument; and then repair the leak(s).

- After you repair the leaks, connect the hose to the instrument and apply the same pressure test and check again for leaks with soapsuds.

- After the instrument passes the soapsuds test, maintain 5 pounds of pressure and close the gas valve screw on the inlet valve.

- Submerge the instrument in a tank of water.

148.33

Figure 8-16.—Testing for leaks.

- Check for slow-rising bubbles which may appear anywhere on the instrument. A few hours may elapse before any bubbles are visible.

- Mark the leak(s) as soon as you remove the instrument from the tank; then repair them. Follow up by appying 5 psi test pressure, and submerge the instrument in the tank again to double check for leaks.

When you are certain there are no leaks in the instrument, remove it from the tank, dry the exterior with a clean, soft cloth, and recharge it to exactly 5 pounds. Twenty-four hours later, attach a pressure gage to the gas inlet valve of the instrument and check its pressure. If it has dropped, repeat either the soapsuds test or the tank test as often as necessary until you find the leak(s). Then make necessary repairs. The instrument is now ready for drying and charging.

Drying and Charging

To dry and charge the instrument with nitrogen:

- Reconnect the outet hose from the dryer to the inlet valve on the instrument.

- Open the outlet valve of the instrument.

- Turn on the nitrogen at 5 pounds of pressure and let it cycle through the entire instrument.

- Purge the instrument by holding a finger over the outlet valve. When the gage on the dryer shows a pressure up to, but not exceeding 5 pounds, remove your finger from the outlet valve and allow the gas to escape from the instrument. At about 5-minute intervals, during a period of approximately 1/2 hour, repeat the purging operation.

- When you have the instrument purged (completely free of moisture), replace the outlet valve screw, and let the pressure on the dryer build up to approximately 2 pounds, or as indicated in the overhaul manual for the instrument.

- When the pressure reaches the specific amount, close and secure the gas valve screw (large one) on the gas inlet valve and disconnect the hose from the optical instrument. Turn off the nitrogen bottle and replace the small, inlet screw in the charging valve.

Some moisture-tight instruments have inlet and outlet screws (not valves) which can be used for purging the instrument, but not for pressure testing.

Pressure-tight instruments must undergo a special testing procedure. Check with your instructor or shop supervisor for the instructions and specifications applicable to a particular pressure-tight instrument.

Securing the Equipment

A special procedure must be followed for securing the equipment. The following procedure is intended to protect both you and the equipment.

- Close the cylinder valve. The pressure readings on both gages should drop to zero if the hose line is open.

- Turn the pressure-adjusting control screw counterclockwise until it is loose.

- Disconnect the hoses to the instrument dryer from the regulator.

- Disconnect the cylinder from the regulator by unscrewing the union-joint nut on the coupling. Then replace the cap on the nitrogen cylinder.

- If a regulator is to be out of service for several weeks or longer, screw in the pressure-adjusting control screw just enough to relieve the spring pressure on the valve seat. At this point the control screw will no longer be loose. This aids in lengthening the life of the valve seat. Before the regulator is used again, the control screw must be loosened as prescribed in the setting up procedure.

Pressure Testing and Charging Rangefinders

Pressure testing and charging rangefinders are quite similar to procedures described for gas-tight instruments, with the following exceptions:

- Only helium is used to charge and test rangefinders. The inlet and outlet valves, located next to each other, are painted orange or yellow to indicate helium.

- The rangefinder is too large to be submerged to test for leaks, so be extremely observant when using soapsuds on all fittings, access covers, and optics.

- A large volume of helium must be used during the purging operation, so be sure you have a sufficient supply on hand.

- Adjust the regulator to allow 7-10 pounds of pressure to flow from the helium bottle. Observe the gage on the instrument dryer to allow no more than 5 pounds of pressure in the rangefinder during pressure testing or purging.

- After the rangefinder has been purged for 1/2 hour, use a helium purity indicator to test the percentage of helium in the instrument. See figure 8-17.

- To use the indicator, run helium directly from the gas cylinder through the indicator. Adjust the pointer to show a reading of 100% while helium is flowing directly from the

11.99:.100(148)B

Figure 8-17.—Running helium through the rangefinder and the purity indicator.

cylinder. Now re-attach the hoses from the helium cylinder to the instrument dryer, and attach a hose from the outlet valve on the rangefinder to the helium purity indicator. Continue purging the rangefinder until the helium purity indicator shows 97.5% helium, then secure the charging operation. Seal the rangefinder with 2 pounds of pressure.

In all cases of handling compressed gas, follow the rules outlined herein and always exercise caution.

Charge all gas- and pressure-tight instruments with gases and pressures specified for them, at the times stated below:

1. Prior to the conclusion of each ship's overhaul.
2. When inspection indicates condensation on internal optical surfaces.
3. Immediately after completion of an overhaul of an optical instrument.
4. At the completion of twelve months of service.

General Safety Procedures

Some general rules to follow when you recharge an optical instrument are:

NEVER recharge an optical instrument when the temperature is below 32° F.

NEVER charge an instrument with nitrogen or helium after the pressure in the bottle or tank falls below 400 pounds per square inch.

Recharge each instrument with only the type of gas and pressure specified for that particular instrument. If in doubt, use nitrogen, and pressurize the instrument to 2 pounds.

When the inlet valve or the area near it is painted ORANGE or YELLOW, always charge the instrument with HELIUM.

CHAPTER 9

MACHINE TOOL OPERATION

It has long been recognized that optical and mechanical problems are two phases in the single problem of repairing optical instruments. Machine tool operation requires a knowledge of certain mechanical principles that apply to all machine work. These are the principles of cutting tools, cutting speeds, and feeds, and actions of gears, screws, and cams. All of these principles are applied in the construction of machines and used during various machine operations. The mechanical principles may be few, but there is no end to the methods of application in machine tool work.

As an Opticalman in the Navy, you will often be working on vital instruments with no available replacement parts and special tools. When this situation arises, you must be prepared to manufacture the part or tool you need.

This chapter gives a description of the machine tools common to optical shops, and it will help you to gain a working knowledge of the machining operations you will be required to perform. First and foremost, you must remember:

NO JOB IS SO IMPORTANT AND NO SERVICE IS SO URGENT THAT YOU CANNOT TAKE TIME TO PERFORM YOUR WORK SAFELY.

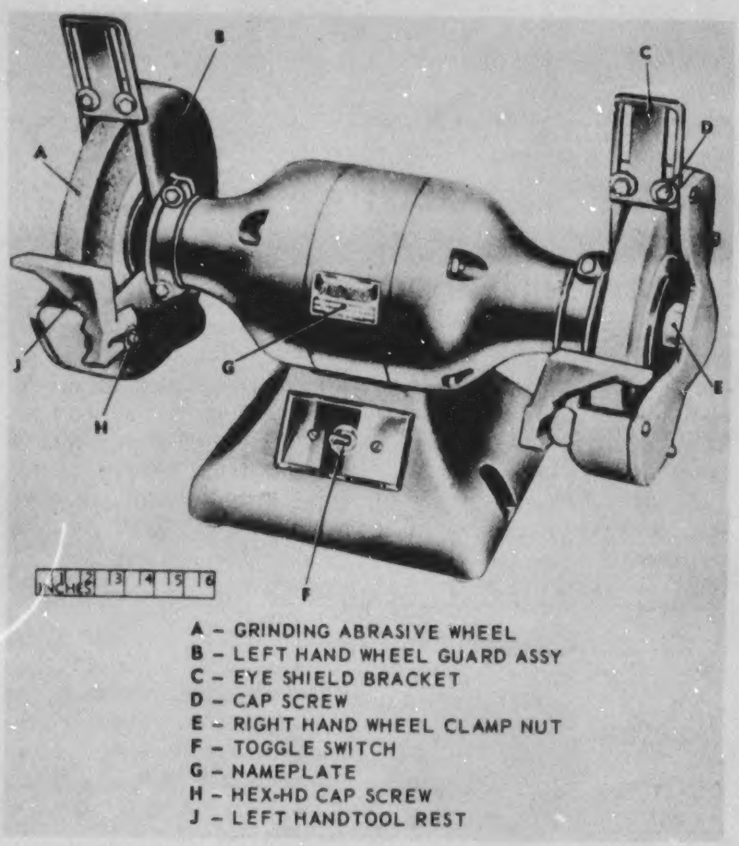
GRINDERS

Grinding is the removal of metal by the cutting action of an abrasive. Offhand grinding is a term that describes the manual holding and manipulation of a workpiece that is being ground. To grind accurately and safely, using the offhand method, you must have experience. In addition, you must know how to select and install grinding wheels and how to sharpen or dress them. You MUST have a knowledge of the safety precautions concerning grinding.

To properly grind small handtools, single-edged cutting tools, and twist drills, you must understand the terms used to describe the angles and surfaces of the tools, you must know for which operations each tool is used, and you must know the composition of the tool material and the abrasive wheel.

Bench grinders are relatively simple machines. The main components of these grinders are: a motor with an extended shaft for mounting grinding wheels, a mounting base for the motor, grinding wheel guards mounted over the grinding wheel as a safety feature, a provision for coolants, an adjustable toolrest to steady the workpiece, and a shield fastened to the wheel guards to protect the operator from flying chips.

Figure 9-1 shows a representative bench grinder. The grinding wheel on the left is usually a coarse, general purpose wheel used for rough work or for removing large amounts of metal. The wheel on the right is a fine, finishing wheel which will produce a polished appearing surface. Grinding wheels up to 8 inches in diameter and 1 inch in thickness are normally used on bench grinders.



44.61

Figure 9-1.—Bench grinder.

GRINDING SAFETY

Since the grinding wheel is a fragile cutting tool which operates at high speeds, we must place great emphasis on the safe operation of grinders. Observance of safety precautions, posted on or near all grinders used by the Navy, is mandatory for the safety of the operator and the safety of personnel in the vicinity.

What are the most common sources of injury during grinding operation? Grit, generated by the grinding process is the most common source and causes the most serious injuries—eye injury. Bodily contact with the wheel causes abrasions which are quite painful and can be serious. Segments of an exploded wheel or a tool "kicked" away from the wheel cause cuts and bruises which can become infected if not protected from grit and dust from the grinding.

Safety in using grinders is primarily a matter of using common sense and concentrating on the job at hand. Each time you start to grind a tool, stop briefly to consider how observance of safety precautions and the use of safeguards protect you from injury. Consider how handicapped you would be if you lost your sight or lost or mutilated an arm or hand.

1. Read posted safety precautions BEFORE you start to use a machine.

2. Secure all loose clothing and remove rings or other jewelry.

3. Inspect the grinding wheel, wheel guards, toolrest, and other safety devices to ensure that they are in good condition and are positioned properly. Set the toolrest so that it is within 1/8 inch of the wheel face and level with the center of the wheel. For small work, the rest can be positioned within 1/16 inch of the wheel.

4. Clean the transparent shields on the grinder, and put on goggles. Transparent shields are NOT a substitute for goggles. Dust and grit may get around a shield, but goggles give full eye protection. WEAR GOGGLES AT ALL TIMES during grinding operations.

5. When starting the grinder, stand aside until operating speed is reached to prevent injury in case the wheel explodes from a defect that has not been noticed.

6. Use light pressure when beginning a job. Too much pressure on a cold wheel may cause failure.

7. Grind only on the face or periphery of a grinding wheel, unless the grinding wheel is specifically designed for side grinding.

8. Use the coolant frequently while grinding. Dip the work often in water to prevent overheating and loss of temper (in most metals you will grind). Dipping also keeps the work cool enough to hold in your hand.

9. The primary purpose of the bench grinder in optical shops is to sharpen steel cutting tools and form special handtools from ferrous metals. It is NOT used to grind any nonferrous metal because the wheel will collect the ground metal, causing accidents and spoilage when used to grind steel. Nonferrous metals like aluminum, brass, or Monel collect in the wheel and actually force themselves into the pores of the wheel. If this metal is allowed to build up, it could crack the wheel, causing it to disintegrate at operating speed. ALWAYS check the wheel of any grinder to be sure that no metal has adhered to the wheel. When metal has collected on the wheel of a grinder, the wheel should be dressed down with a proper dressing tool until it is completely free of foreign particles.

GRINDING WHEELS

The abrasive particles in a grinding wheel provide thousands of small cutting edges that remove metal chips from the stock being ground. For most efficient use of a grinding wheel, you must select the correct wheel and ensure that it is installed properly.

The two basic elements of a grinding wheel are the abrasive and the bond. The abrasive performs the cutting action, and the bond cements the abrasive grains into a wheel shape. Approximately 40% of the composition of a grinding wheel is made up of the abrasive and another 40% of the bond. The remaining 20% is empty space between abrasive grains.

Abrasives

There are two types of abrasives: natural and manufactured. Natural abrasives, such as emery, corundum, and diamond are used only in honing stones and in special types of grinding wheels. The common manufactured abrasives are aluminum oxide and silicon carbide. They have superior qualities and are more economical than natural abrasives. Aluminum oxide (designated by the letter A) is used for grinding steel and steel alloys and for heavy duty work such as cleaning steel castings. Silicon carbide (designated by the letter C), which is harder but not as tough as aluminum oxide, is used mostly for grinding nonferrous metals and carbide tools.

Bond

The bond determines the strength of the wheel. The most common types of bonds are the vitrified and the silicate. The vitrified bond (designated by V) is most common. It is a glasslike substance that makes a strong rigid grinding wheel which is porous, free cutting, and unaffected by temperature, oils, water, and acids. The silicate bond (designated by the letter S) is softer (releases abrasive grains more readily) than the vitrified bond. Silicate bond is used when heat generated in the grinding process must be kept to a minimum, as in grinding edged tools.

In general, the softer materials to be ground require harder bonds and coarse grain size, and the harder materials require softer bonds and fine grain size. A proper bond for a specific grinding application should retain the abrasive grains until they become dull.

Grain Size, Grade, and Structure

Other terms used in relation to grinding wheels are grain size, grade, and structure. The grain size (from 24 to 600) indicates the size of the abrasive grains in a wheel. It is determined by the size of mesh of a sieve through which the grains can pass.

The grade (designated alphabetically A to Z, soft to hard) of a grinding wheel is the term that designates the ability of the bond to retain the abrasive grains in the wheel. In the grinding operation, a soft grade bond releases the abrasive grains relatively easily as compared to a hard grade bond.

The structure (designated numerically from 1 to 15, dense to porous) indicates the spacing between the abrasive grains.

A standard wheel marking, combining the letter and number symbols given in the preceding paragraphs, is used for selection. For example:

A 36 K 10 V

Abrasive type

Grain size

Grade

Structure

Bond type

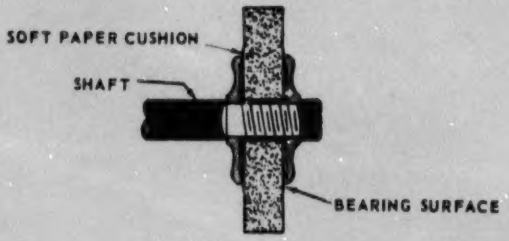
For more detailed information relating to grinding wheels, refer to *Tools and Their Uses*, NAVEDTRA 10085 series.

GRINDING WHEEL INSTALLATION

The wheel of a bench grinder must be properly installed; otherwise, accidents may occur and the wheel will not operate properly. Before installing a wheel, inspect it for visible defects, and "sound" it by tapping lightly with a piece of hardwood to determine whether it has invisible cracks. A good wheel gives a clear ringing sound when tapped; a cracked wheel gives a dull thud.

Ensure that the wheel fits on the spindle without play. Do not use force, however, as this may cause the wheel to crack when placed in operation, or it may cause the wheel to be slightly out of axial alignment. Recessed flanges (fig. 9-2) must be used on both sides of the wheel to spread the pressure of the securing nut. The flanges should be at least one-third the diameter of the wheel. Use thin cardboard or rubber washers between the flanges and the wheel to ensure even pressure on the wheel and to dampen vibration between the wheel and shaft when the grinder is in operation. Tighten the securing nut enough to hold the wheel firmly; tightening too much may damage the wheel.

NOTE: The right end of a grinder shaft uses a right-hand thread. The left end has a left-hand thread.



28.62

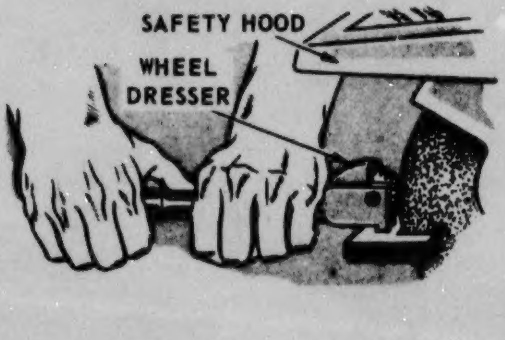
Figure 9-2.—Method of mounting a grinding wheel.

GRINDING WHEEL MAINTENANCE

Like other cutting tools, the cutting surfaces of grinding wheels require frequent reconditioning to perform efficiently. Dressing is the term that describes the process of cleaning the periphery of grinding wheels. Dressing breaks away dull abrasive grains and smooths the surface so that there are no grooves. Truing is the term that describes the dressing of the cutting face of the wheel so that the resultant surface runs absolutely true to the grinding wheel shaft.

The wheel dresser (fig. 9-3) is used for dressing grinding wheels. To dress a wheel with this tool, start the grinder and let it come up to speed. Set the wheel dresser on the rest as shown in figure 9-3, and bring it in firm contact with the wheel. Move the wheel dresser across the face of the wheel until the surface is clean and square with the sides of the wheel.

If grinding wheels get out of balance because of out-of-roundness, dressing the wheel will usually remedy the condition. After dressing a wheel, reset the clearance between the wheel and toolrest. If the wheel gets out of balance axially, it probably will not affect the efficiency of the wheel on bench and pedestal grinders. This unbalance may be remedied simply by removing the wheel and cleaning the shaft, spindle, and spindle hole in the wheel and the flanges.



28.63

Figure 9-3.–Using a grinding wheel dresser.

GRINDING METHODS

Successful offhand grinding requires patience, concentration, and a light touch. Practice on noncritical grinding jobs will develop your skill and increase your confidence so that you can handle any job required.

The way you stand while grinding is very important. You should keep your feet slightly spread, with weight evenly distributed, so you can comfortably move in any direction and still see the work and the action of the grinding wheel.

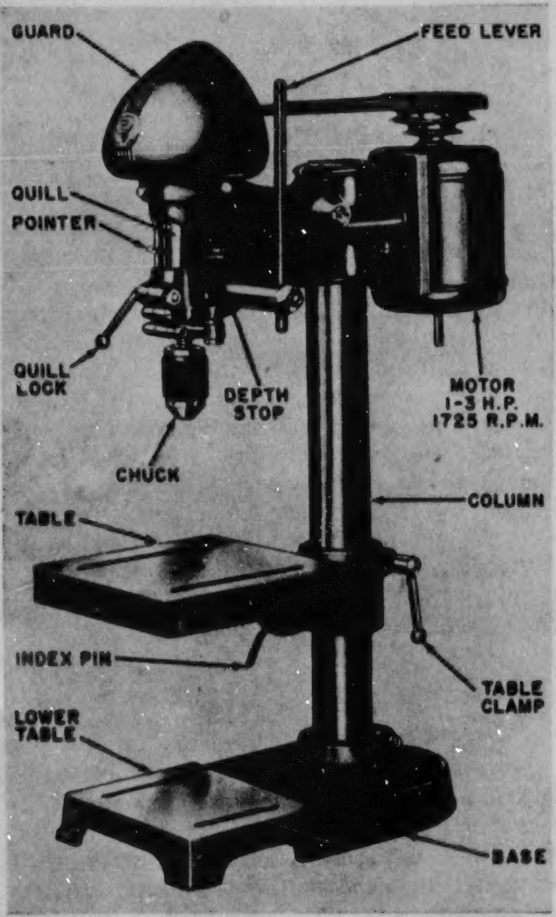
The toolrest should be square and level with the face of the grinding wheel, with no dents or nicks on the edge or surface. In many grinding operations, you slide the work across the top of the rest or across the edge, so there can be no restrictions to free movement.

Coordination is essential in precision grinding. One hand holds the work to apply steady pressure against the wheel, while the other hand guides the work to produce the desired contour. At the same time, you should move the work back and forth across the face of the wheel to prevent grooving. Since any type of grinding produces heat, you must frequently quench the work in water. When you resume grinding, you must develop a "feel" for the work to pick up where you left off and avoid destroying previous efforts. Methods for grinding various tools are illustrated in *Tools and Their Uses*, NAVEDTRA 10085 series.

DRILL PRESSES

Although drilling machines or drill presses are commonly used by untrained personnel, you cannot assume that operating these machines proficiently is simply a matter of inserting the proper size drill and starting the machine. As an Opticalman, you will be required to perform drilling operations with a great degree of accuracy. You must be well acquainted with the machine and the methods of operation of drill presses and drills found in Navy shops.

The sensitive drill press.(fig. 9-4) is used for drilling small holes in work under conditions which make it necessary for the operator to "feel" what the cutting tool is doing. The tool is fed into the work by a very simple device—a lever, a pinion and shaft, and a rack which engages the pinion. These drills are nearly always belt driven because the vibration caused by gearing would be undesirable. Sensitive drill presses are used in drilling holes less than one-half inch in diameter. The high-speed range of these machines and the holding devices used make them unsuitable for heavy work.

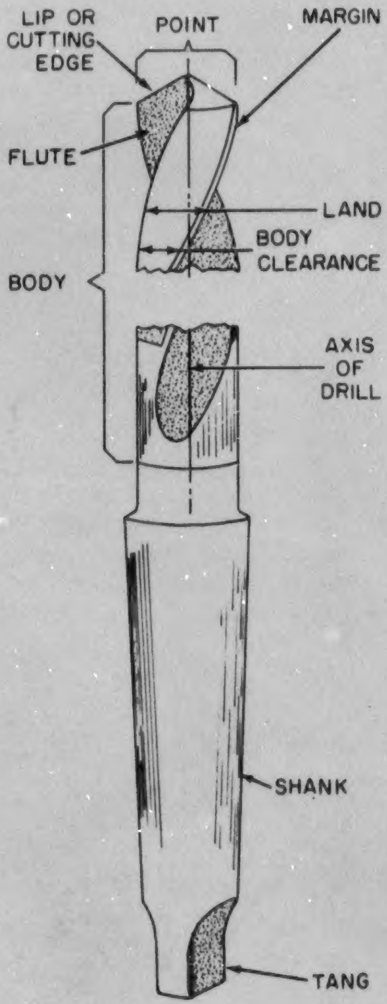


4.29

Figure 9-4.—Drill press.

DRILLS

In figure 9-5 you see the principal parts of a twist drill: the BODY, the SHANK, and the POINT. The portion of the LAND behind the MARGIN is relieved to provide BODY CLEARANCE. The body clearance assists in the reduction of friction during drilling. The LIP is the cutting edge, and the area behind the lip is ground away to provide lip clearance which



44.20(11)

Figure 9-5.—The parts of a twist drill.

allows the drill to advance into the work. The CHISEL POINT is the sharp edge located at the tip of the drill, which separates the two cutting edges. The WEB of the drill is the metal column which separates the flutes. It runs the entire length of the body between the flutes and gradually increases in thickness toward the shank, giving additional rigidity to the drill.

The TANG is found only on tapered shank drills. It fits into a slot in the spindle of the drill press and bears a portion of the driving strain. Its principal purpose is to make it easy to remove the drill from the socket with the aid of a drill drift. (NEVER use a file or screwdriver to do this job.)

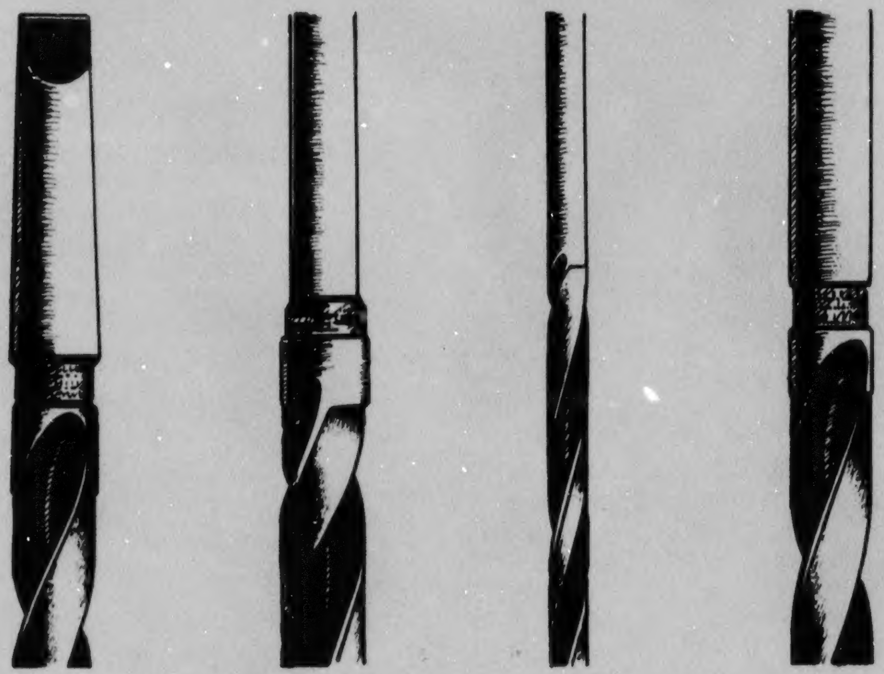
The SHANK fits into the spindle, or chuck, of the drill press. There are several types of shanks, the most common of which are shown in figure 9-6.

Twist drills are made of cobalt alloy or high-speed steel, and they are capable of cutting any metal softer than that from which they are made. For cutting extremely hard materials, carbide inserts are silver soldered to the cutting lips of a drill.

Figure 9-7 shows a typical plastic cutting drill and a typical metal cutting drill. Note the smaller point angle on the drill used for working with plastics.

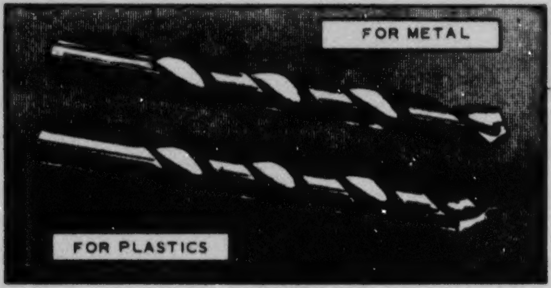
Figure 9-8 shows the standard dimensions and clearances of a twist drill. You can reduce the point angle and increase lip clearance for soft metals and plastics, or increase the point angle and reduce lip clearances for metals which are difficult to drill.

Drill sizes are indicated in three ways: by inches, letter, and number. The nominal inch sizes run from 1/64 inch to 4 inches or larger, in 1/64-inch steps. The letter sizes run from "A" to



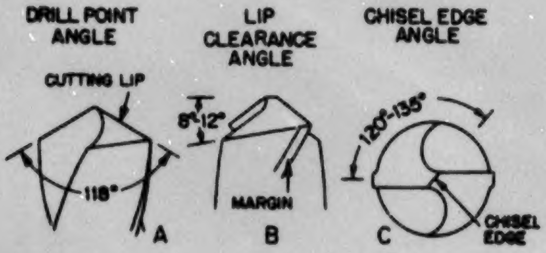
44.20(11)

Figure 9-6.—Four popular shanks.



44.20(11)

Figure 9-7.—Comparison of a twist drill for plastics with one for metals.



44.205

Figure 9-8.—Specifications for grinding a regular point twist drill.

"Z" (0.234 inch to 0.413 inch). The number sizes run from No. 80 to No. 1 (0.0135 inch to 0.228 inch). Number size drills are used most often in optical shops.

DRILLING OPERATIONS

The drill press is the first machine tool you will learn to operate. It is relatively simpler to operate and understand than other machine tools in the shop, but skill and accuracy in its use are just as important as for any machine. The drill press and hand held drills are used by an Opticalman more than all other machine tools combined. The skill that you develop in using a drill will often determine whether an optical instrument is made serviceable or is scrapped.

Speeds and Feeds

Experience will help you in selecting the best feeds and speeds for drilling. While you are learning, it is best to start slowly and use the following suggestions.

The correct cutting speed for a job depends upon the degree of machinability of the metal, the size of the drill, the speed, and the type of drill used. The following cutting speeds are recommended for using high-speed drills.

Metal	fpm
Alloy steel	50-70
Machine steel	70-100
Cast iron	70-150
Brass	200-300

The cutting speed of a drill is expressed in feet per minute (fpm), computed by multiplying the circumference of the drill (in inches) by the revolutions per minute (rpm) of the drill. The result is divided by 12. For example, a 1/2-inch drill with a circumference of approximately 1 1/2 inches turning at 100 rpm has a cutting speed of approximately 13 feet per minute.

$$\text{fpm} = \frac{\text{circumference X speed (rpm)}}{12}$$

$$\text{fpm} = \frac{(3.14 \text{ X } 0.5) \text{ X } 100}{12}$$

$$\text{fpm} = \frac{157}{12} = 13.08$$

This cutting speed is quite low compared with the table above. Work the formula using a speed of 400 rpm and see what happens.

The FEED of a drill is the rate of penetration into the work for each revolution. Feed is expressed in thousandths of an inch per revolution. In general, the larger the drill, the heavier the feed that may be used. Always decrease feed pressure as the drill breaks through the bottom of the work to prevent drill breakage and rough edges on the work. The rate of feed also depends on the size and speed of the drill, the material being drilled, and the rigidity of the setup.

Drill presses used in the optical shop are normally limited to four to six different spindle speeds (controlled by V-belts and step pulleys). The deciding factor in selecting a particular spindle speed is the size of the drill and the recommended cutting speed of the metal being drilled. If your drill press is capable of operating at 550, 1500, 2100, and 2700 rpm, what speed would you select to drill brass with a 1/4-inch drill?

$$200 \text{ fpm} = \frac{(3.14 \times 0.250) \times (\text{rpm})}{12}$$

DRILLING HINTS

Many factors contribute to successful drilling. Among these are spindle speeds, rate of feed, selecting a properly sharpened drill, clamping of the work, and the basic accuracy of the drill chuck.

1. Before any drill can start a hole, the spot to be drilled must be center punched. The center punch mark will keep the point of the drill from "walking away" and at the same time provide a depression for the cutting lips to bite into.

2. Select the correct size drill for the hole you wish to make. For small holes (1/4 inch or less) you can use the same size drill. For larger holes, or when extreme accuracy is necessary, use a smaller pilot drill followed by the finished size drill. At times, you can improve the accuracy of a hole by starting the hole with a center drill (fig. 9-9). Even a perfectly sharpened drill will produce a hole several thousandths of an inch oversize. When a drill has been ground with unequal length cutting lips, you may end up with a .005- to .015-inch oversize hole with small drills.

28.57X

Figure 9-9.–Combined drill and countersink (center drill).

3. Chuck the drill securely in the drill press and turn your machine on and off to check for runout (eccentricity). If the drill wobbles, there could be a burr on the drill shank, chips in the chuck or drill press spindle, or a bent drill. To correct the condition, first examine the drill shank. Small burrs can be filed or ground away and the drill can still be used. Next clean the chuck and drill press spindle hole. If the drill still wobbles, you probably have a bent drill. The working parts (fluted) of a drill are brittle, but the shank is usually softer and can be carefully tapped into alignment with a hammer handle.

4. You are now ready to clamp your work for drilling. Work can be clamped directly to the table with straps and holddown bolts; it can be held in a machinist's vise, or clamped to V-blocks. Always mount the work so the drill will not touch the table or vise when it goes through the work.

The work must be secured to prevent spinning and to prevent the work from jumping as the drill passes through the bottom. Either event could be disastrous to the operator or bystanders. No one should be willing to take the chance of losing several fingers or having a chest slashed by a piece of rotating metal or by being hit with a flying vise.

As you are clamping the work, position the center punch mark directly under the drill point. Small, light pieces tend to center themselves if you bring the drill down to the punch mark. For heavier stock, check the drill head on and 90° either left or right as you set the point on the punch mark. If the drill bends, tap the work into alignment with a mallet, then clamp it down.

NOTE: Always wear eye protection when drilling.

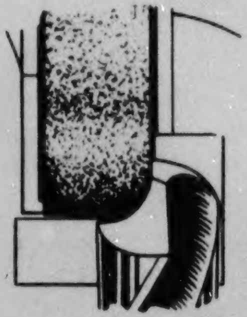
Now start the drill press and lightly touch the work with the drill. Check for perfect alignment and make any corrections necessary before proceeding with the hole.

5. As previously mentioned, when using a sensitive drill press, you can feel what the drill is doing. Generally, fingertip pressure is sufficient for most small drilling operations. Pay attention to sound, vibration, and chips produced. Let the drill do the work. If you force a small drill too rapidly into the work, overheating will be the least of your problems. You do not want to have to explain to your shop supervisor why a $500 component is ruined because you broke a $1 drill in a hole.

If the drill squeaks while in use, you are operating it at too high a speed, metal has built up on the margin, the drill is dull, or there is insufficient lip clearance. When you hear a snapping sound while using a small drill, the drill is turning too slowly, or there is too much lip clearance.

6. For drilling brass or steel, the drill cutting edge should be modified as shown in figure 9-10. Grinding the cutting lip surface parallel with the axis of the drill strengthens the cutting surface, prevents digging in, and greatly reduces the possibility of chipped lips or broken drills.

After a drill has been sharpened repeatedly, the chisel point will become wider due to the tapered web construction. When this happens, it is difficult to start a drill in a center punched hole. The web thickness can be reduced by grinding as shown in figure 9-10 except that the drill should be held at a slight angle from vertical.



44.20AA.1

Figure 9-10.—Grinding a twist drill for brass or steel.

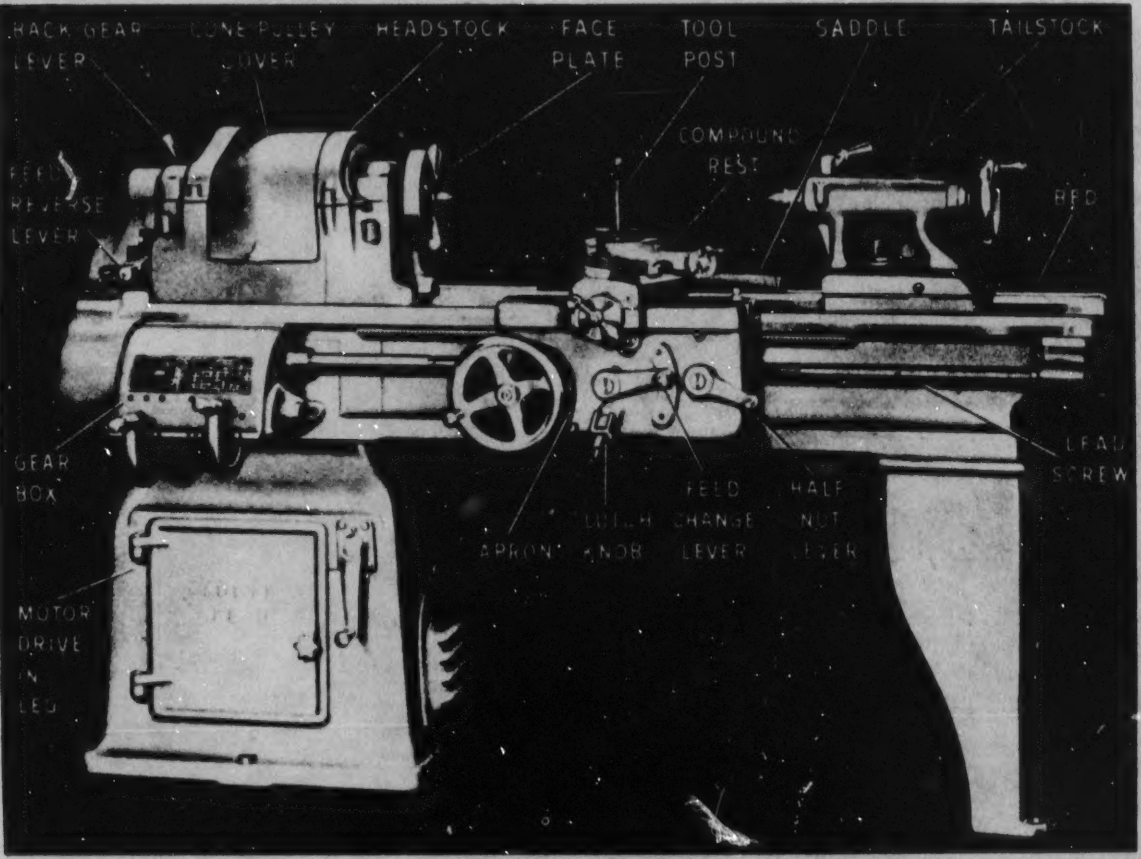
Cutting Lubricants

Lubricants serve several important functions during drilling. They reduce heat and friction, carry chips out of the work, and provide a smoother hole. Some shallow drilling can be done dry with a sharp drill, especially in brass and aluminum; however, cutting oil is essential with hard steel. Brass and aluminum tend to build up on the margin of a drill during dry drilling. This will cause galling which ruins the drill and the hole. For best results, use a lubricant. A thin solution of soluble oil is very effective.

LATHES

An engine lathe such as the one shown in figure 9-11, or one similar to it, is found in every optical shop, however small. It is used principally for turning, boring, facing, and thread cutting, but it may also be used for drilling, reaming, knurling, and grinding. The work held in the engine lathe can be revolved at a number of different speeds, and the cutting tool can be accurately controlled by hand or power for longitudinal and crossfeed. (Longitudinal feed is movement of the cutting tool parallel to the axis of the lathe; crossfeed is movement of the cutting tool perpendicular to the axis of the lathe.)

Lathe size is determined by two measurements: (1) diameter of work it will swing over the bed and (2) length of the bed. For example, a 14-inch X 6-foot lathe will swing work up to 14 inches in diameter and has a bed 6 feet long. Engine lathes are built in various sizes, ranging from small bench lathes with a swing of 6 inches to very large lathes for turning work of large diameter, such as large turbine rotors. The average size of lathes found in optical shops is 8 to 16 inches.



28.69X(75)

Figure 9-11.–An engine lathe.

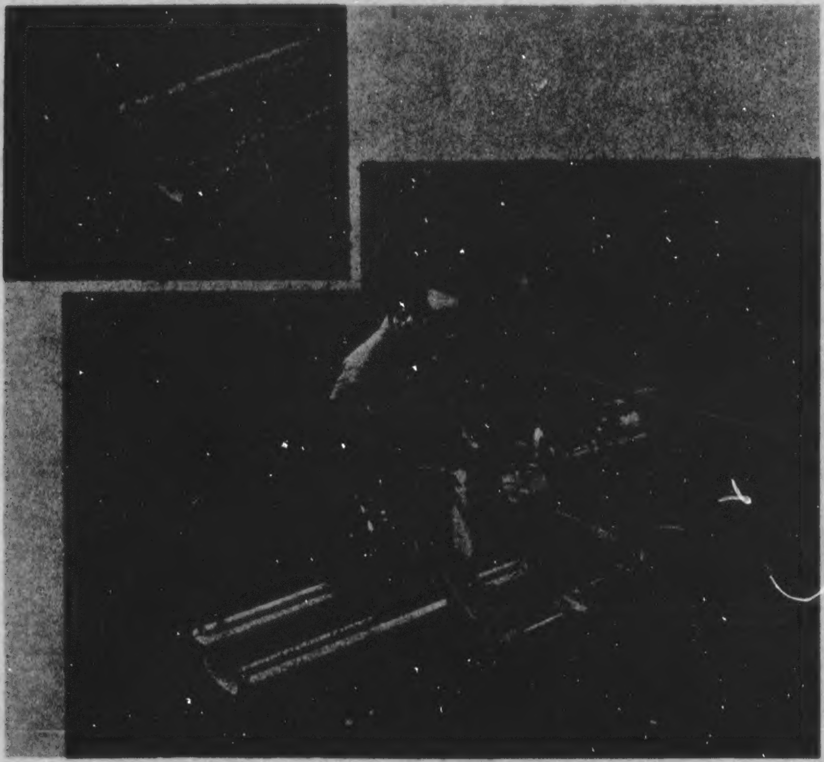
PRINCIPAL PARTS

To learn the operation of a lathe, you must first become familiar with the names and fuctions of the principal parts. In studying the principal parts in detail, remember that lathes of different manufacture differ somewhat in details of construction, but all are built to provide the same general functions. As you read the description of each part, find its location on the lathe by referring to figure 9-11. For specific details on the features of construction and operating techniques, refer to the manufacturer's technical manual for the machine you are using.

Bed

The bed is the base or foundation of the working parts of the lathe. Its main features are the ways which are formed on its upper surface and run the full length of the bed. Ways provide the means for maintaining the tailstock and carriage, which slide on them, in alignment with the headstock, which is permanently secured by bolts.

Figure 9-12 shows the ways of a typical lathe. The inverted V-shaped ways 1, 3, and 4, and the flat way 2, are accurately machined parallel to the axis of the spindle and to each other. The V-ways are guides that allow



28.70X

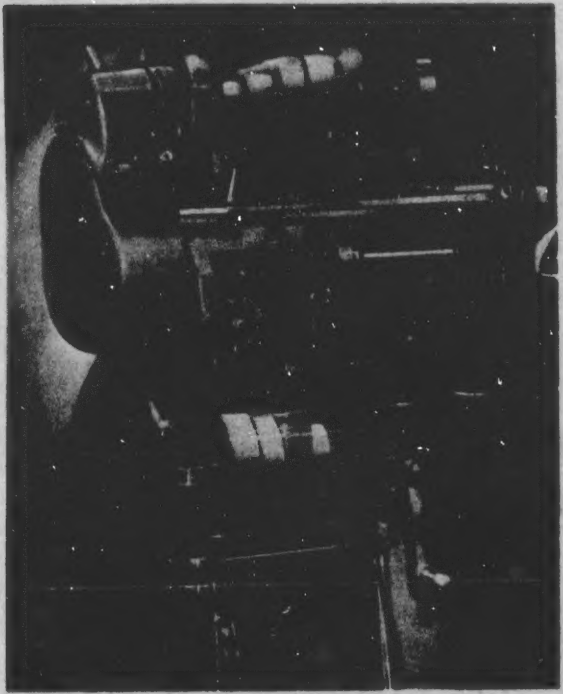
Figure 9-12.—Rear view of lathe.

movement over them in a longitudinal direction only. The headstock and tailstock are aligned by the V-ways. The flat way, number 2, takes most of the downward thrust. The carriage slides on the outboard V-ways (1 and 4), which, because they are parallel to number 3, keep it in alignment with the headstock and tailstock at all times—an absolute necessity if accurate lathe work is to be accomplished. Some lathe beds have two V-ways and two flat ways while some others have four V-ways.

For satisfactory performance a lathe must be kept in good condition. A common fault of careless machinists is to use the bed as an anvil for driving arbors, or as a shelf for hammers, wrenches, and chucks. NEVER allow anything to strike the ways or damage their finished surface in any way. Keep them clean and free of emery dust and chips. Wipe them off daily with an oiled rag to help preserve their polished surface.

Headstock

The headstock carries the headstock spindle and the mechanism for driving it. In the belt-driven type (fig. 9-13) the driving mechanism consists merely of a step pulley that drives the spindle directly or through back gears. When being driven directly, the spindle revolves with the pulley; when being driven through the back gears, the spindle revolves more slowly than the pulley, which, in this case, turns freely on the spindle. Thus two speeds are obtainable with each position of the belt on the pulley; if the pulley has four steps as illustrated, eight spindle speeds can be obtained.



28.71X

Figure 9-13.—Belt-driven type headstock.

The geared headstock (fig. 9-14) is more complicated but more convenient to operate, because speed can be changed by the mere shifting of gears. It is similar to an automobile transmission except that it has more gear shift combinations and therefore a greater number of speed changes. A speed index plate attached to the headstock indicates the lever positions for the different spindle speeds. Always stop the lathe when shifting gears to avoid possible damage to gear teeth.

The headstock casing is filled with oil for lubricating the gears and shifting mechanism contained within it. Those parts not immersed in the oil are lubricated by the splash produced by the revolving gears. You must keep the oil up to the level indicated on the oil gage and drain and replace it when it becomes dirty or gummy.

The headstock spindle is the rotating element of the lathe and is directly connected to the work which revolves with it. The spindle is supported in bearings at each end of the headstock through which it projects. The nose of the spindle holds the driving plate, faceplate, or chuck. The spindle is hollow throughout its length so that bars or rods can be passed through it and held in a chuck at the nose. The chuck end of the spindle is bored to a Morse taper to receive the live center. A gear at the other end of the spindle drives the feed and screw-cutting mechanism through a gear train located on the left end of the lathe.

The spindle is subjected to considerable torque because it not only drives the work against the resistance of the cutting tool but also drives the carriage that feeds the tool into the work. For that reason adequate lubrication and accurately adjusted bearings are absolutely necessary. (Bearing adjustment should be attempted only by an experienced lathe repairman.)

Tailstock

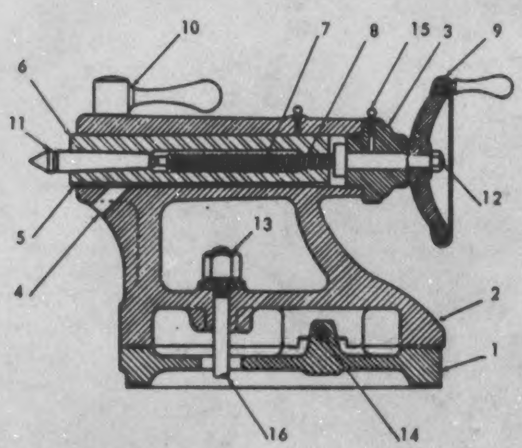
The primary purpose of the tailstock (fig. 9-15) is to hold the dead center to support one end of work being machined. However, it can also be used to hold tapered shank drills, reamers, and drill chucks. It is movable on the ways along the length of the bed to accommodate work of varying lengths and can be clamped in the desired position by the tailstock clamping nut (13).

The dead center (11) is held in a tapered hole (bored to a Morse taper) in the tailstock spindle (6). You can move the spindle back and forth in the tailstock barrel for longitudinal adjustment by the handwheel (9), which turns the spindle-adjusting screw (7) in a tapped hole in the spindle at (8). The spindle is kept from revolving by a key at (4) that fits a spline or keyway (5) cut along the bottom of the spindle as shown. A binding clamp (10) locks the spindle in place after final adjustment.

The tailstock body is made in two parts. The bottom or base (1) is fitted to the ways; the top (2) is capable of lateral movement on its base. Setscrews provide close adjustment for this lateral movement. Zero marks scribed on the base and top indicate the center position.

28.72X

Figure 9-14.—Sliding gear type headstock.



1.	Tailstock base	9.	Handwheel
2.	Tailstock top	10.	Spindle binding clamp
3.	Tailstock nut	11.	Dead center
4.	Key	12.	End of tailstock screw
5.	Keyway (in spindle)	13.	Tailstock clamp nut
6.	Spindle	14.	Tailstock set-over
7.	Tailstock screw	15.	For oiling
8.	Internal threads in spindle	16.	Tailstock clamp bolt

28.75X

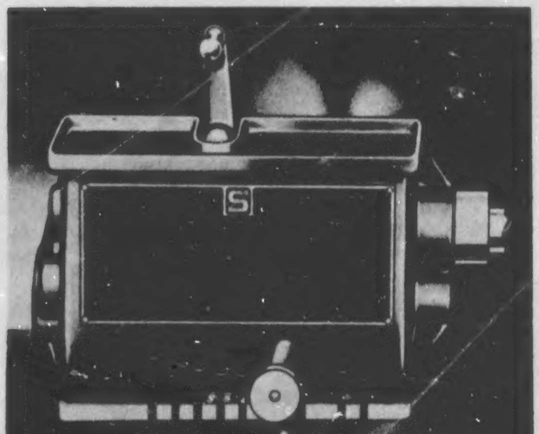
Figure 9-15.—Cross section of a tailstock.

Before inserting a dead center, drill, or reamer, carefully clean the tapered shank and wipe out the tapered hole of the spindle. When holding drills or reamers in the tapered hole of a spindle, be sure they are tight enough so they will not revolve. If allowed to revolve, they will score the tapered hole and destroy its accuracy.

Quick-Change Gears

To do away with the inconvenience and loss of time involved in removing and replacing change gears, most modern lathes are equipped with a self-contained change gear mechanism commonly called the QUICK-CHANGE GEARBOX. There are a number of types used on different lathes but they are all similar in principle (fig. 9-16).

The mechanism consists of a cone-shaped group of change gears. You can instantly connect any single gear in the gear train by a sliding tumbler gear controlled by a lever. This cone of gears is keyed to a shaft which drives the lead screw directly or through an intermediate shaft. Each gear in the cluster has a different number of teeth and produces a different gear ratio when connected in the train. To increase the range, other changes in the gear train can be made by sliding gears which multiply the number of different ratios obtainable with the cone of change gears described above. All changes are made by shifting appropriate levers or knobs. An index plate, or chart, mounted on the gear box indicates the position for placing the levers to obtain the necessary gear ratio to cut the thread or produce the feed desired.



28.87X

Figure 9-16.–Quick-change gearbox.

Carriage

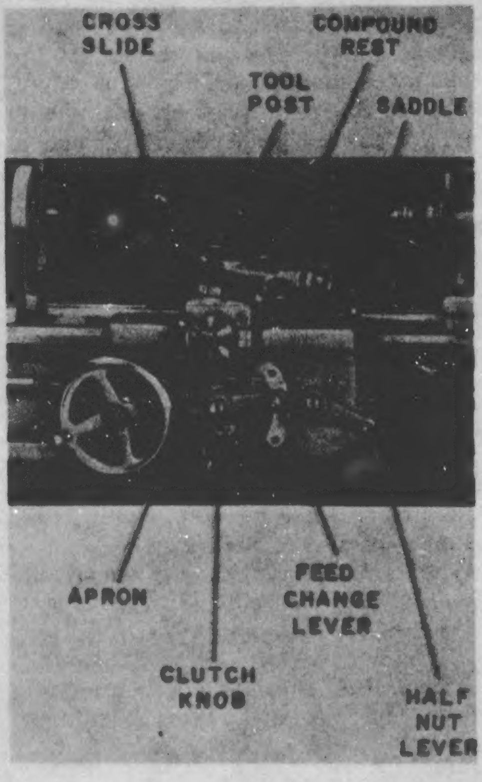
The primary duty of the carriage assembly is to support the cutting tool and move it with extreme accuracy in whatever direction required to machine a piece of work. The accuracy of cuts made parallel to the lathe bed is dependent upon the trueness of the ways; the accuracy of cross and angular cuts depends upon the precision that is built into the carriage.

Figure 9-17 shows the construction of a carriage and the major components of the carriage: saddle, cross-slide, apron and compound rest.

SADDLE.–The saddle, when viewed from the top, is shaped like the letter H. The two arms have inverted V's machined in them which fit over the ways and guide the movement of the carriage along the ways.

CROSS-SLIDE.–The cross-slide of the carriage moves the cutting tool at right angles to the ways. The cross-slide is mounted to the top of the saddle by a dovetail which allows movement across the carriage but prevents side play.

APRON.–Attached to the front of the carriage is the apron. It contains the gearing and mechanism for controlling the movement of the carriage for longitudinal feed and thread cutting and the lateral movement of the cross-slide. You should thoroughly understand the apron before



28.69(75)X
Figure 9-17.—Front view of carriage assembly.

attempting to operate the lathe. Study figure 9-17 very closely as we describe the main parts of the apron.

In general, a lathe apron contains the following:

A longitudinal feed HANDWHEEL for moving the carriage by hand along the bed. This handwheel turns a pinion that meshes with a rack gear secured to the lathe bed. Gear trains driven by the lead screw transmit power from the lead screw to move the carriage along the ways (longitudinal feed) and the cross-slide across the ways (crossfeed), thus providing powered longitudinal feed and crossfeed.

FRICTION CLUTCHES operate by levers on the apron to engage or disengage the power feed mechanism. Most lathes have separate clutches for longitudinal feed and crossfeed, while some lathes have a single clutch for both.

There is a feed change lever for selecting power crossfeed, longitudinal feed or, in the center position, for cutting threads.

A HALF-NUT CLOSURE LEVER engages and disengages the lead screw for cutting threads. The half-nuts fit the thread of the lead screw, which turns in them when they are clamped over it.

COMPOUND REST.—The compound rest (fig. 9-18) is fitted on the top of the cross-slide on a swivel for cutting small tapers and feeding the cutting tool at any angle desired. The top of the compound rest also moves on a dovetail like the cross-slide.

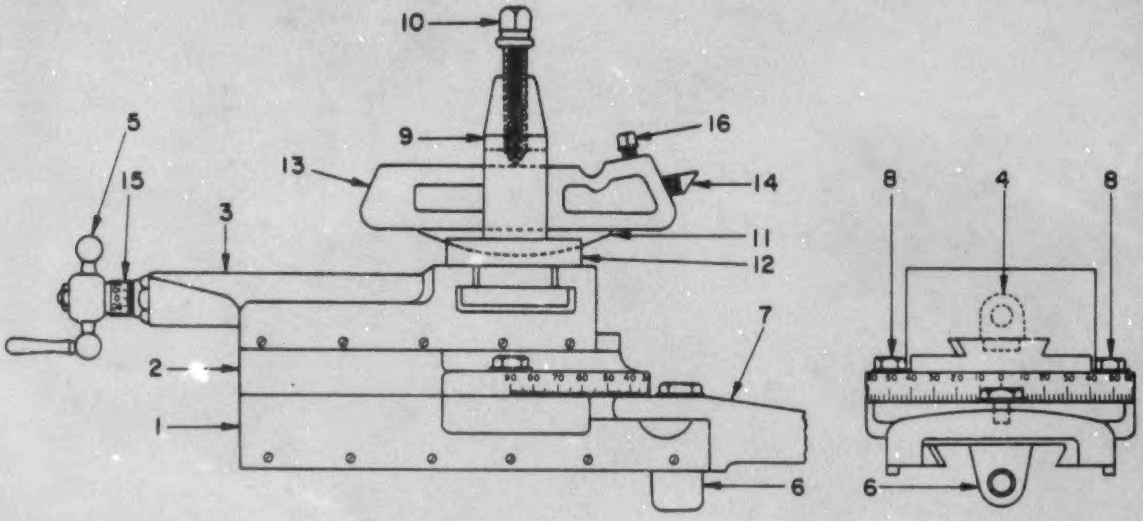
The toolpost, which holds various toolholders, is held in the compound rest by a T-slot.

ATTACHMENTS AND ACCESSORIES

The variety of accessories, or attachments, to a lathe makes it the most versatile machine tool in the shop. In the manufacturer's instruction book, all associated equipment will be listed for the particular lathe installed. In this section we will describe the most common parts that an Opticalman uses.

Chucks

The lathe chuck is a device for holding lathe work. It is mounted on the nose of the spindle. The work is held by jaws which can be moved in radial slots toward the center to clamp down on the sides of the work. The jaws are moved in and out by screws turned by a chuck wrench applied to the sockets at the outer ends of the slots.



1. Cross-slide.
2. Compound rest swivel.
3. Compound rest top.
4. Compound rest nut.
5. Compound rest feed screw handle.
6. Crossfeed nut.
7. Chip guard.
8. Swivel securing bolts.
9. Toolpost.
10. Toolpost setscrew.
11. Toolpost rocker.
12. Toolpost ring.
13. Toolholder.
14. Cutting tool.
15. Micrometer collar.
16. Tool clamp bolt.

28.88X

Figure 9-18.—Compound rest.

The 4-jaw independent lathe chuck (fig. 9-19A) is the most practical chuck for general work. It provides the most clamping power. The four jaws are adjusted one at a time, making it possible to hold work of various shapes and to adjust the center of the work to coincide with the center of the lathe. The jaws are reversible for inside or outside clamping.

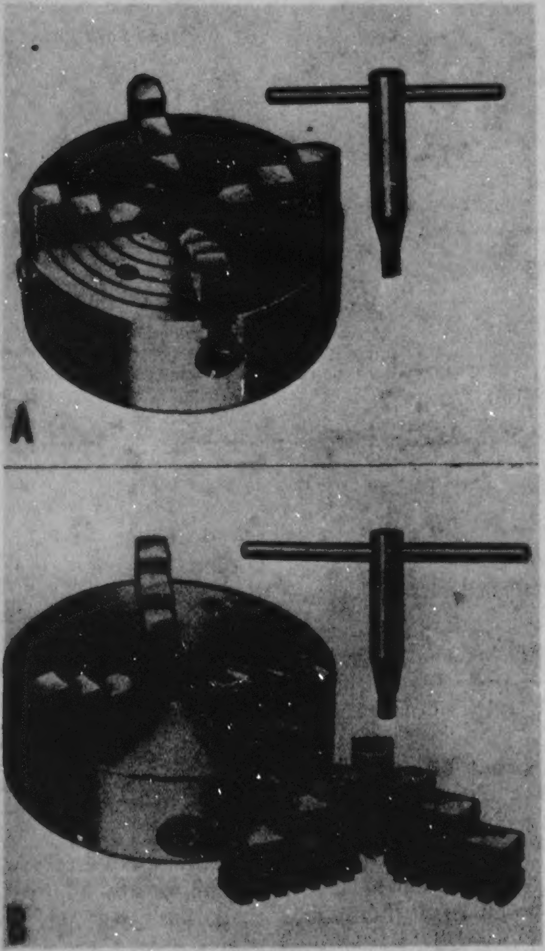
The 3-jaw universal, or scroll, chuck (fig. 9-19B) can be used only for holding round or hexagonal work. It has matched sets of inside and outside jaws. All three jaws are moved in and out together in one operation as the chuck wrench is turned. This chuck is easier and faster to operate than the four-jaw type, but when its parts become worn its accuracy in centering cannot be relied upon. Runout is quite often from .001 to .030 inch. Proper lubrication and constant care in use are necessary to ensure reliability.

When you need to hold small diameter work such as screws, pins, and small rods on a lathe, a small drill chuck such as that shown in figure 9-20 will usually be better suited for the job than the larger chucks previously described. This type of chuck has a Morse taper shank that will fit both the head spindle and the tailstock of the lathe. The drill chuck has universal self-centering jaws that will automatically center the work when it is clamped.

The drill chuck is used to hold center drills and straight shank drills in the tailstock for drilling operations on a lathe.

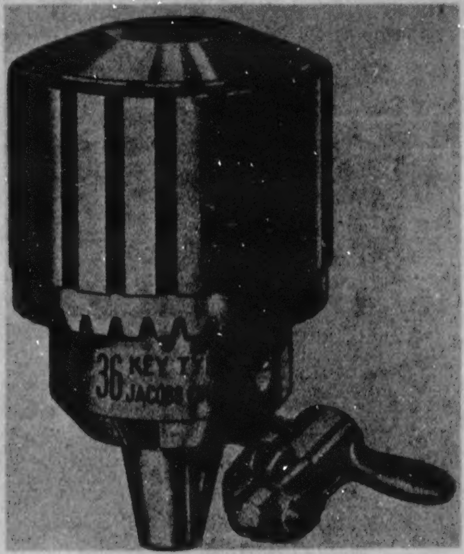
Collets

The best way to accurately hold small work in a lathe is with the draw-in collet. Figure 9-21 shows the collet assembled in place in the lathe spindle. The collet is a self-centering holding



28.90X
Figure 9-19.—A. Four-jaw chuck. B. Three-jaw chuck.

device that is very accurate and most often used for precision work in the optical shop. The collet is a split cylinder with an outside taper that fits into a matching tapered closing sleeve and screws into the threaded end of a hollow draw bar. Turning the hardwheel of the hollow draw bar pulls the collet into the tapered sleeve, thereby closing the collet firmly around the work and centering it in the head spindle. The size of the center hole determines the diameter of the work that can be held. Collets are made with center hole size ranging from 1/64 inch up and graduated in 1/64-inch steps. The best results are obtained when the diameter of the work is the same size as the dimension stamped on the collet.



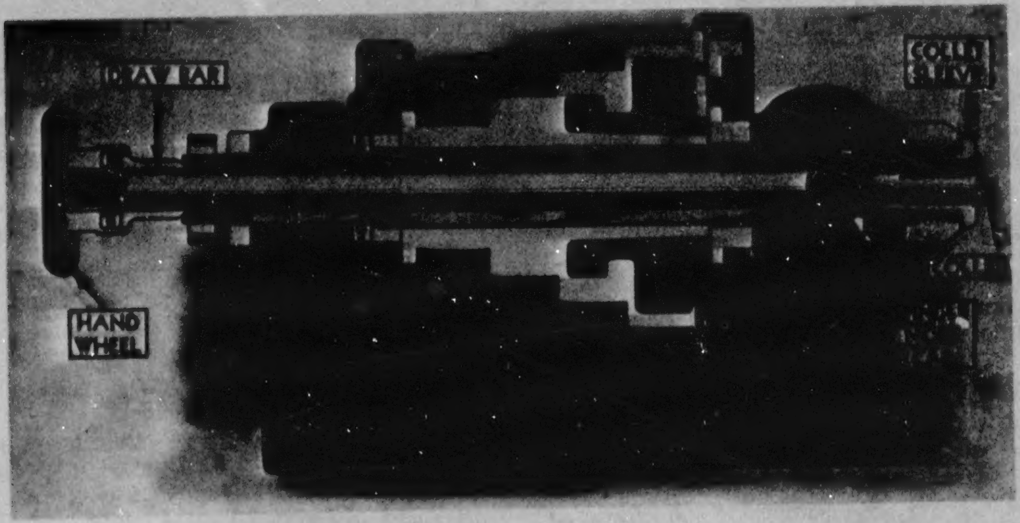
28.92X
Figure 9-20.—Drill chuck.

To ensure accuracy of the work when using the draw-in collet, be sure that the contact surfaces of the collet and closing sleeve are free of chips, dirt, and burrs.

Taper Attachment

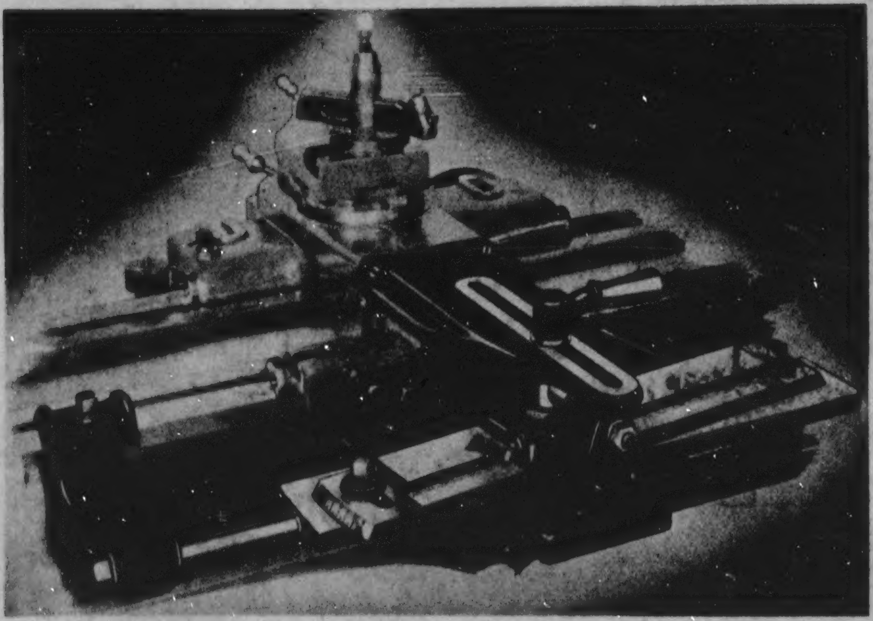
The taper attachment (fig. 9-22) is used for turning and boring tapers. It moves the cross-slide laterally as the carriage moves longitudinally, causing the cutting tool to move at an angle to the axis of the work to produce a taper.

The angle of the taper desired is set on the guide bar of the attachment. One end of the bar is marked in degrees; the other end is marked in inches of taper per foot. The guide bar support is clamped to the lathe bed. Since the cross-slide is connected to a shoe that slides on the guide bar, the tool follows along a line parallel to the guide bar at an angle to the work axis corresponding to the desired taper.



28.91X

Figure 9-21.–Draw-in collet chuck.



28.98X

Figure 9-22.–A taper attachment.

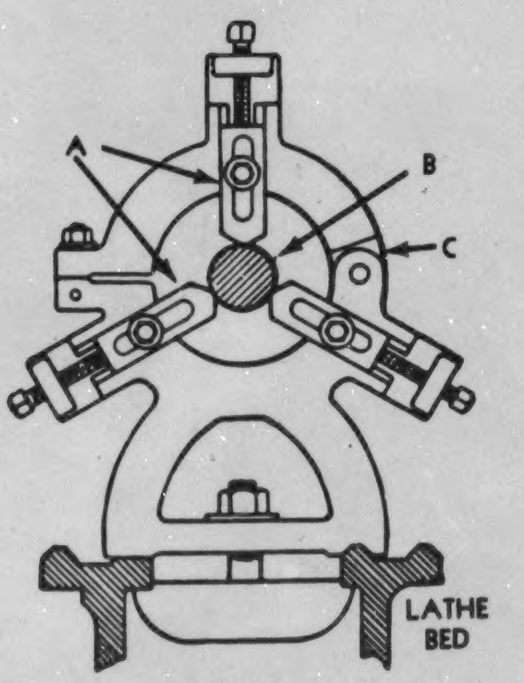
The operation and application of the taper attachment will be explained further in the section on taper turning.

Center Rest

The center rest, also called the steady rest, is used for the following purposes:

1. To provide an intermediate support or rest for long slender bars or shafts being machined between centers. It prevents them from springing undercut or sagging as a result of their otherwise unsupported weight.
2. To support and provide a center bearing for one end of work being bored or drilled from the end when it is too long to be supported by a chuck alone.

The center rest is clamped in the desired position on the bed on which it is properly aligned by the ways, as illustrated in figure 9-23. The jaws (A) must be carefully adjusted and lubricated to allow the work (B) to turn freely and at the same time keep it accurately centered on the axis of the lathe. The top half of the frame is hinged at C for easy positioning without removing the work from the centers or changing the position of the jaws. To set up a center rest, turn a short piece of stock to the same diameter as the work to be supported. Adjust the jaws to bear evenly on the stock, then chuck the actual workpiece and move the rest to the desired location on the lathe bed.

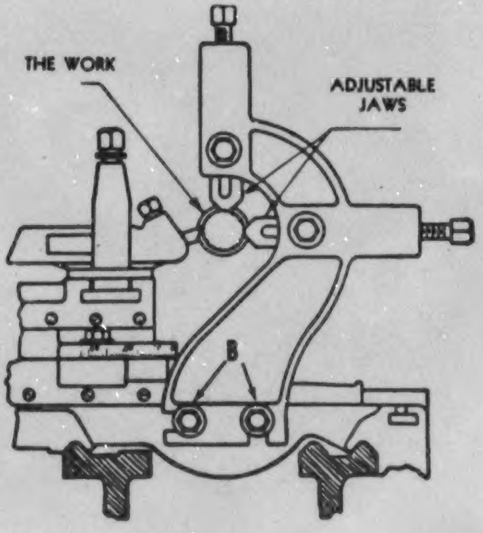


28.96X

Figure 9-23.—Center rest.

Follower Rest

The follower rest backs up work of small diameter to keep it from springing under the stress of cutting. It is named for its function—it follows the cutting tool along the work. As shown in figure 9-24, it is attached directly to the saddle by bolts (b). The adjustable jaws bear directly on the finished diameter of the work opposite the cutting tool. As with the center rest, lubrication is necessary to prevent marring of the work.



28.97X

Figure 9-24.—Follower rest.

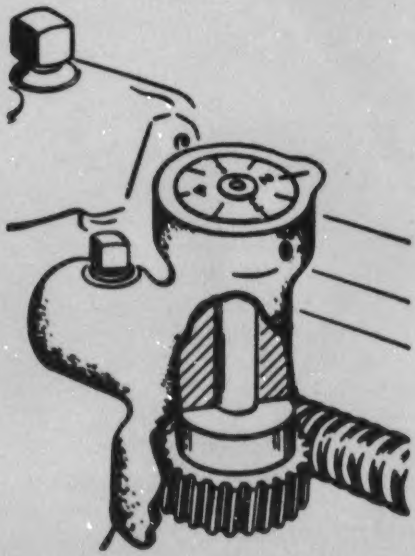
Thread Dial Indicator

The thread dial indicator (fig. 9-25) eliminates reversing the lathe to return the carriage to the starting point to catch the thread at the beginning of each successive cut. The dial, which is geared to the lead screw, indicates when to clamp the half-nuts on the lead screw for the next cut.

The threading dial consists of a worm wheel attached to the lower end of a shaft and meshed with the lead screw. The dial is the upper end of the shaft. As the lead screw revolves, the dial turns and the graduations on the dial indicate points at which the half-nuts may be engaged.

Carriage Stop

You can attach the carriage stop to the bed at any point where you want the carriage to stop. It is used mainly for turning, facing, or boring duplicate parts, as it eliminates repeated measurements of the same dimension. In operation, you set up the stop at the point where you want to stop the feed. Just before reaching this point, shut off the automatic feed and carefully run the carriage up against the stop. Carriage stops come with or without micrometer adjustment. Figure 9-26 shows a micrometer carriage stop.



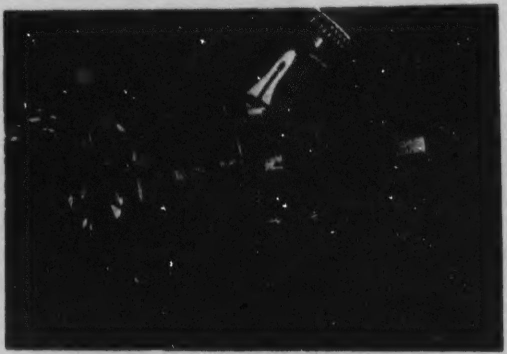
28.99X

Figure 9-25.–Thread dial indicator.

NOTE: Some carriages have a stop which automatically stops the carriage by disengaging the feed or stopping the lathe. This type of stop is called AUTOMATIC CARRIAGE STOP, and it is usually a built-in feature of the lathe design.

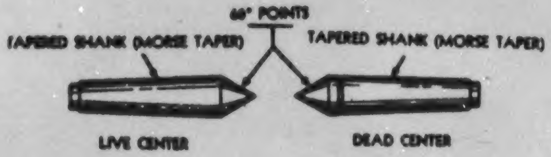
Lathe Centers

The 60° lathe centers, shown in figure 9-27, hold the work between points so it can be turned accurately on its axis. The headstock spindle center is called the LIVE center because it revolves with the work. The tailstock center is called the DEAD center because it does not turn. A dead center, mounted in ball bearings, is



28.100

Figure 9-26.–Micrometer carriage stop.



28.93

Figure 9-27.–60° lathe centers.

available for most lathes. This center does turn with the work. Both live and dead centers have shanks turned to a Morse taper to fit the tapered holes in the spindles; both have points finished to an angle of 60°. They differ only in that the dead center is hardened and tempered to resist the wearing effect of the work revolving on it. The live center revolves with the work, and it is usually left soft. The dead center and live center must never be interchanged.

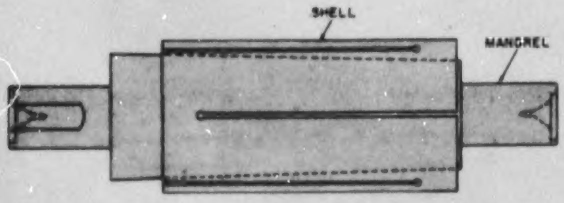
NOTE: There is a groove around the hardened tail center to distinguish it from the live center.

The centers fit snugly in the tapered holes of the headstock and tailstock spindles. If chips, dirt, or burrs prevent a perfect fit in the spindles, the centers will not run true.

To remove the headstock center, insert a brass rod through the spindle hole and tap the center to jar it loose; you can then pick it out with your hand. To remove the tailstock center, run the spindle back as far as it will go by turning the handwheel to the left. When the end of the tailstock screw bumps the back of the center, it will be forced out of the tapered hole.

Mandrels

As an Opticalman, very often you will machine a part that must have all its finished external surfaces running true with a hole which extends through it. You can best accomplish this operation by holding the part to be machined on a mandrel. There are several types of mandrels used by machinists, but the most common mandrel used in the optical shop is the expansion mandrel (fig. 9-28). The expansion mandrel is composed of two parts: a tapered pin, which is turned between centers, and a split shell, which is tapered on the inside to fit the tapered pin. As the tapered pin is pressed into the split shell, the shell expands evenly to grip the work firmly. Be very cautious when pressing in the tapered pin, so that you do not exert too great a pressure on the work.



28.116

Figure 9-28.—A split-shell expansion mandrel.

CUTTING TOOLS

It would be extremely difficult to name one particular part or accessory of a lathe as being the most important to overall lathe operation. It is, however, very easy to realize that the cutting tool most affects the quality of the work done on a lathe. You must keep the cutting tools sharp and have them ground properly, or the finished product will be of inferior quality, and in most cases, useless.

Most of the functions connected with operating a lathe are automatic features built into the design of the machine. The cutting tool is not one of these features. You must acquire the knowledge to design the proper tool and the skill to grind cutting tools from tool blanks. The major factors in designing and grinding a cutting tool are the properties of the material to be cut, the type of cut to be taken, and the composition of the cutting tool.

The majority of machine work done in optical shops is a special setup/one-piece operation, so the cutting tools are usually made of high-speed steel.

You should remember that a metal cutting tool actually "pushes" the metal apart. As a result, the pressures exerted on the cutting tool at its cutting edge are extremely high, and the pressure increases as the rate of feed and depth of cut increase. The pressure causes friction which in turn causes heat to be generated.

The pressure exerted on the cutting tool is necessary because it makes the cutting action possible. The objective, therefore, is to produce a cutting tool with an edge that will require a minimum amount of pressure to force it through the metal and still withstand the cutting pressure without breaking or wearing. To follow this discussion on grinding cutting tools, you must have a full understanding of the terminology used to describe the cutting tool.

Cutting Tool Nomenclature

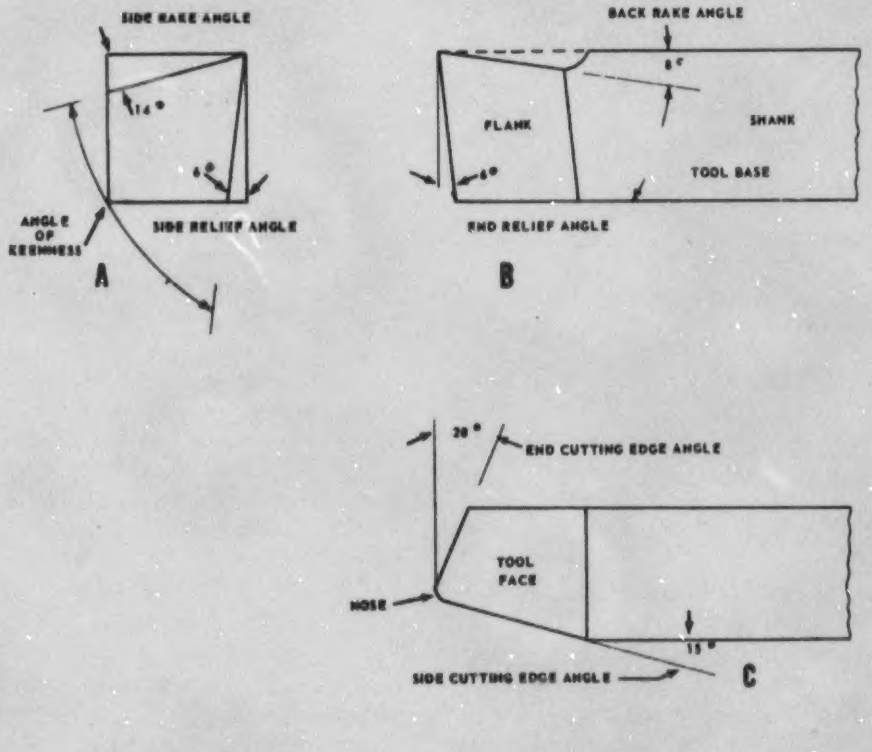
A tool blank is an unground piece of toolstock. After it is ground, it is called a tool bit. Tool blanks are available in sizes from 1/8 to 1 inch square and in proportional lengths from about 2 to 8 inches. The part of the tool behind the cutting edge is called the shank. The terms right-hand tool and left-hand tool are applied to tool bits in relation to the direction they move across the work piece. If a tool cuts while moving from right to left (as you see it, standing in front of the machine), it is a right-hand tool. A left-hand tool is just the opposite.

Figure 9-29 shows the application of angles and surfaces used in discussing single-edge or single-point cutting tools.

Side rake (fig. 9-29A) is the angle at which the face of the tool is ground away with respect to the top surface of the tool bit. The amount of side rake influences to some extent the size of the angle of keenness. It causes the chip to "flow" to the side of the tool away from the cutting edge. For cutting aluminum, increasing the side rake angle will produce better results. Steel is easier to machine when the side rake is decreased.

The side relief (fig. 9-29A) is the angle at which the side or flank of the tool is ground so that the cutting edge leads the flank surface during cutting. The total of the side rake and side relief subtracted from 90° equals the angle of keenness. A tool with proper side clearance concentrates the side thrust on the cutting edge rather than on the flank of the tool.

The end relief (fig. 9-29B) is the angle at which the end surface of the tool is ground so



28.64

Figure 9-29.—Applications of tool terminology.

that the end face edge of the tool clears the work being turned.

The back rake (fig. 9-29B) is the angle at which the face is ground with respect to a plane parallel with the top surface of the tool. It is ground primarily to cause the chip cut by the tool to "flow" back toward the shank of the tool and away from the work. Back rake may be positive or negative; it is positive if it is sloped downward from the nose of the tool toward the shank, and negative if the angle is reversed. When you grind a tool bit, you must hold the tool blank against the grinding wheel so that you form the side rake and back rake at the same time.

Most toolholders you will use position the tool bit at a 16 1/2° angle from horizontal. You must take this factor into account when grinding back rake. In some cases you will have to grind a negative back rake on the tool bit to achieve the correct overall rake.

The side cutting edge angle (fig. 9-29C) is ground to prevent the point of the tool from digging into the workpiece which would probably result in pulling the tool into the workpiece deeper than intended. The end cutting edge angle is ground so that the end face edge of the tool does not drag over the machined surface.

Note the radius on the tool nose in figure 9-29C. For rough turning, a radius of 1/64 inch is effective for most optical shop applications; a radius of 1/32 inch for both rough and finish work is quite satisfactory.

Tool Grinding Procedure

The following steps apply to all types of lathe tool bits.

1. Form the side cutting edge angle and side relief.
2. Grind the end cutting edge angle, nose radius, and end relief.
3. Grind the side rake and back rake angles.

NOTE: Tool bits are extremely hard, so considerable grinding will be necessary. Quench the tool frequently to prevent overheating.

4. After carefully grinding all faces of the tool bit, hone the cutting surfaces with an oilstone. This step ensures smoother cutting action and prolongs tool life.

Figure 9-30 shows a variety of commonly used lathe tool bits and their applications. The tool design preferred for most turning operations, however, is one similar to that shown in figure 9-29.

Figure 9-31 shows the toolholders used in optical shops. Either left-hand or right-hand tool bits and threading tools can be held in the straight shank toolholder. The left-hand toolholder is used for right-hand bits, the right-hand toolholder is used with left-hand bits.

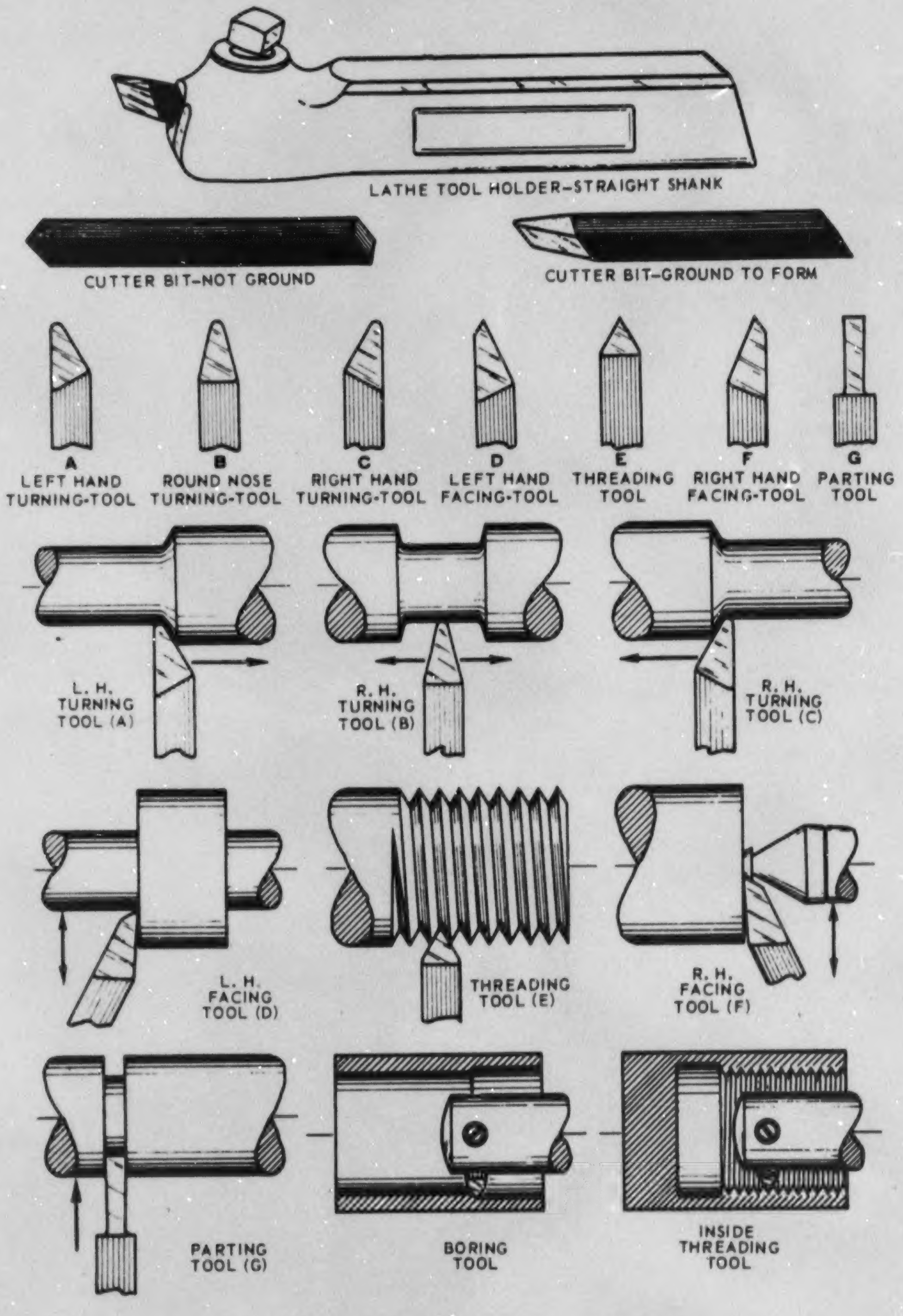
KNOWLEDGE OF OPERATION

Before attempting to operate any lathe, be sure you know how to run it. Read all operating instructions that come with the machine. Learn the location of the various controls and how to operate them. When you are satisfied that you know how they work, check to see that the spindle clutch and the power feeds are disengaged and start the motor. Then become familiar with all phases of operation, as follows:

1. Shift the speed change levers into the various combinations; start and stop the spindle after each change. Get the feel of this operation.

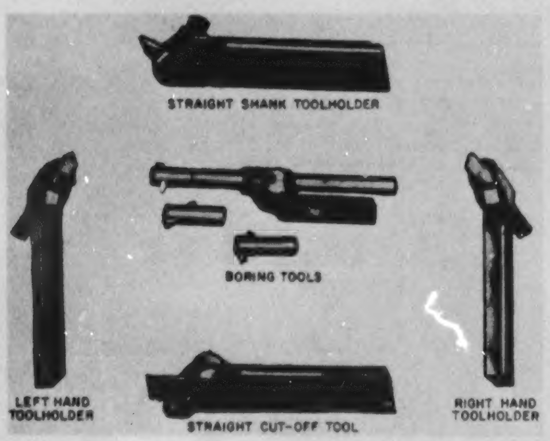
2. Before engaging either of the power feeds, operate the hand controls to be sure that the parts involved are free for running. With the spindle running at its slowest speed, try out the operation of the power feeds, and observe their action. Be careful not to run the carriage too near the limits of its travel, and NEVER allow the compound rest to run into a rotating chuck. Learn how to reverse the direction of feeds, how to disengage them quickly, and how to stop the spindle quickly.

3. Try out the operation of engaging the lead screw for thread cutting. Remember that you must disengage the carriage feed mechanism before you can close the half-nuts on the lead screw.



28.66

Figure 9-30.—Lathe tools and their applications.



28.67

Figure 9-31.—Common type of toolholders.

4. Practice making changes with the quick-change gear mechanism by referring to the thread and feed index plate on the lathe you intend to operate. Remember that you can make changes in the gear box with the lathe running slowly, but you must stop the lathe for spindle speed changes.

Do not treat your machine roughly. When you shift gears for changing speed or feed, remember that you are putting solid gear teeth into mesh with each other; feel the gears into engagement. Disengage the clutch and stop the lathe before shifting.

5. Always wear eye protection when operating a lathe.

Speeds and Feeds

CUTTING SPEED is the rate at which the surface of the work passes the point of the cutting tool. It is expressed in feet per minute.

To find the cutting speed, multiply the circumference of the work (in inches) by the number of revolutions it makes per minute (rpm) and divide by 12 (circumference = diameter X 3.1416). The result is the peripheral or cutting speed in feet per minute (fpm). For example, a 2-inch diameter piece turning at 100 rpm will produce a cutting speed of

$$\frac{(2 \times 3.1416) \times 100}{12} = 52.36 \text{ fpm}$$

FEED is the amount the tool advances in each revolution of the work. It is usually expressed in thousandths of an inch per revolution of the spindle. The index plate on the quick-change gear box indicates the setup for obtaining the feed desired. The amount of feed to use is best determined from experience.

Cutting speeds and tool feeds are determined by a variety of methods: the hardness and toughness of the metal being cut; the quality, shape, and sharpness of the cutting tool; the depth of the cut; the tendency of the work to spring away from the tool; and the strength and power of the lathe. Since conditions vary, it is good practice to find out what the tool and work will stand, and then select the most practical and efficient speed and feed consistent with the finish desired.

If the cutting speed is too slow, the job takes longer than necessary and often the work produced is unsatisfactory. On the other hand, if the speed is too great, the tool edge will dull quickly and frequent grinding will be necessary.

The cutting speeds possible are greatly affected by the use of a suitable cutting lubricant. For example, steel which can be rough turned dry at 60 fpm can be turned at about 80 fpm when flooded with a good cutting lubricant.

Some of the recommended, approximate cutting speeds for various metals, using high-speed steel bits, are shown below.

Metal	Roughing cut (fpm)	Finishing cut (fpm)	Thread-cutting (fpm)
Cast iron	60	80	25
Machine steel	100	150	35
Tool steel	50	75	20
Brass	150	200	50
Bronze	90	100	25
Aluminum	250	400	50

Rough Cuts

When roughing parts down to size, use the greatest depth of cut and feed per revolution that the work, the machine, and the tool will stand at the highest practical speed. On many pieces, when tool failure is the limiting factor in the size of roughing cut, it is usually possible to reduce the speed slightly and increase the feed to a point that the metal removed is much greater. This will prolong tool life. Consider this example: the depth of cut is 1/4 inch, the feed is .020 inch per revolution, and the speed is 80 fpm. If the tool will not permit additional feed at this speed, it is usually possible to drop the speed to 60 fpm and increase the feed to about .040 inch per revolution without having tool trouble. The speed is, therefore, reduced 25% but the feed increased 100%, so that the actual time required to complete the work is less with the second setup.

Finish Cuts

On the finish turning operation a very light cut is taken, since most of the stock has been removed on the roughing cut. You can usually use a fine feed, making it possible to run at a higher surface speed. A 50% increase in speed over the roughing speed is commonly used. In any event you should run the work as fast as the tool will withstand to obtain the maximum speed in this operation. Be sure to use a sharp tool when finish turning.

Lubricants

A cutting lubricant serves two main purposes–it cools the tool by absorbing a portion of the friction heat produced by the cutting action, and it lubricates the cutting edge to prevent a buildup of metal. A cutting lubricant also keeps the chips flushed away from the tool.

The best lubricants for cutting metal must often be determined by experiment. Ordinary petroleum base oil is often used, but soluble oil mixed with varying amounts of water are usually suitable for most metals–especially when coolant action rather than lubrication is desired. Other cutting lubricants marketed under various names, are also used, but these are expensive and used mainly in manufacturing where high-cutting speeds are the rule.

The usual lubricants for turning metals are:

Metal	Lubricant
Cast iron	Usually worked dry
Mild steel	Oil or 5% solution of soluble oil
Hard steel	Mineral lard oil or 10% solution of soluble oil
Monel metal	Mineral lard oil or 20% solution of soluble oil
Bronze	Dry or 5% solution of soluble oil
Brass	Dry (kerosene is sometimes used on the hard composition)
Aluminum	Dry or kerosene or a 5% solution of soluble oil

For threading, a lubricant is more important than for straight turning. Mineral lard oil is recommended for threading in all steels and cast iron, and kerosene mixed with oil for aluminum and brass.

Maintenance

Maintenance is an important part of operational procedure for lathes. The primary requisite is PROPER LUBRICATION. Make it a point to oil your lathe daily where oil holes are provided. Oil the ways daily–not only for lubrication but to protect their scraped surfaces. Oil the lead screw often while it is in use to preserve its accuracy. A worn lead screw lacks precision in thread cutting. Be sure the headstock is filled up to the oil level; drain out and replace the oil when it becomes dirty or gummy. If your lathe has an automatic oiling system for some parts, be sure all those parts are getting oil. Make it a habit to CHECK frequently for lubrication of all moving parts.

Do NOT neglect the motor just because it may be out of sight; check its lubrication. If it does not run properly, notify the Electrician's Mate whose duty it is to care for it. He will cooperate with you to keep it in good condition. In a machine that has a belt drive from the motor to the lathe, avoid getting oil or grease on the belt when oiling the lathe or motor.

Keep your lathe CLEAN. A clean and orderly machine is an indication of a good mechanic. Dirt and chips on the ways, on the lead screw, and on the crossfeed screws will cause serious wear and impair the accuracy of the machine. When you polish work on a lathe with emery cloth, protect the ways with rags or paper.

NEVER put wrenches, files, or other tools on the ways.

NEVER use the bed or carriage as an anvil. Remember that the lathe is a precision machine and nothing should be allowed to destroy its accuracy.

LATHE OPERATION

The basic function of a lathe is to remove metal, by means of a suitable cutting tool, from a piece of work which is securely supported and made to revolve. This basic function is applied to general lathe operations for straight turning, taper turning, boring, facing, drilling, and thread cutting.

The wide range of operations that can be performed on a lathe makes it the most valuable machine tool available. Up to this point, you have studied the construction of a lathe, the accessories and the various tools used on it. Now you will be given additional information to combine the tools and the machinery for effective applications.

It is important that you study the blueprint of the piece to be manufactured before you begin machining. Check over the dimensions and note the points or surfaces from which they are laid out. Plan the steps of your work in advance to determine the best procedure. Be sure that the stock you intend to use is large enough for the job.

Mounting Work

Accurate machining cannot be performed if work is improperly mounted. Requirements for proper mounting are:

1. The work centerline must be accurately centered with the axis of the lathe spindle.
2. The work must be rigidly held while being turned.
3. The work must not be sprung out of shape by the holding device.
4. The work must be adequately supported against any sagging caused by its own weight and against springing caused by the action of the cutting tool.

There are three general methods for holding work in the lathe for optical shop purposes: (1) between centers, (2) on a mandrel, and (3) in a chuck. The most common chuck used for general optical shop machining is the three-jaw universal. When accurate centering or holding power is not critical, and a rapid setup is desired, the three jaw chuck will be satisfactory for all applications.

Whenever you change chucks, threads and mating surfaces must be perfectly clean and free of chips. Always use a block of wood to cover the ways when installing or removing a chuck.

If a chuck is to be used for holding work, be sure enough stock extends so you do not have to rechuck the work.

Centering the Work

When additional machining is to be done on round stock which is turned to finished size, the most practical method of holding the work is to use a collet. Collets are extremely accurate and need no centering adjustments. If the stock is an odd size or if it will not fit any available collet, use a 4-jaw chuck and dial indicator as shown in figure 9-32.

Place copper or aluminum shims between the stock and chuck jaws to prevent marring of the work, then lightly tighten the jaws. NOTE: Never operate a lathe until you remove the chuck wrench.

Be sure the end of the stock is resting on the face of the chuck if the stock is larger than the center hole in the chuck. Place the point of the indicator on the stock, and spin the chuck slowly to note the amount and direction of runout. The chuck jaws are numbered to make this task easier. When you determine which way to move the stock, remember to loosen the jaw on one side before tightening the opposing jaw, then check runout again.

28.120X

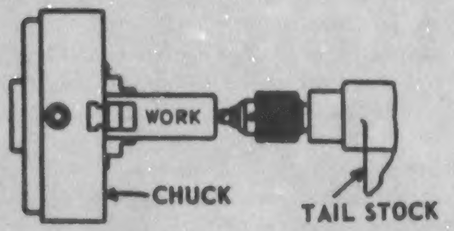
Figure 9-32.—Centering work with a dial indicator.

Centering work in a 4-jaw chuck is generally by trial and error, but with a little practice you can usually eliminate runout with just a few adjustments.

Once the work is running true, take up evenly on all 4 jaws and check runout again. The work must be chucked tightly, but not so tightly as to distort it.

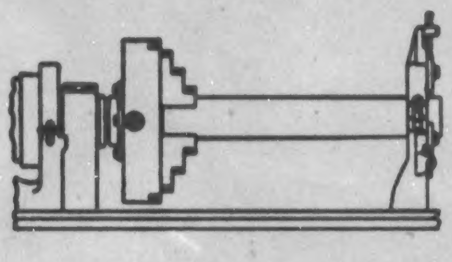
Center Drilling

A center hole must be drilled if the end of a piece of stock is to be drilled or if it is to be held in a center. Figure 9-33 shows the method for center drilling a short shaft. Figure 9-34 shows a long shaft supported with a center rest.



28.111

Figure 9-33.—Drilling center hole.



28.126X

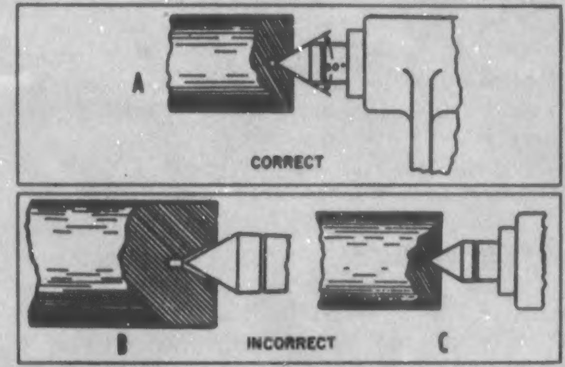
Figure 9-34.—Work mounted in a chuck and center rest.

A correctly formed center hole must support the center and allow clearance for the center point, as shown in figure 9-35A. The dead center is subjected to considerabe friction and pressure so it must be properly lubricated. If center drilling is too deep (fig. 9-35B) or incorrectly shaped (fig. 9-35C) the work will not be adequately supported.

Figure 9-36 shows the correct size center drills to use for various stock diameters.

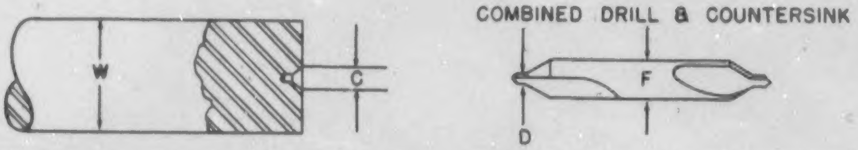
Turning Between Centers

When it is not practical or desired to clamp work in a chuck, or if you are machining a piece held on a mandrel, turning between centers will be necessary. Always align the centers as shown in figure 9-37 prior to mounting the work. NEVER assume that the centers are already aligned. Even a slight amount of misalignment



28.114X

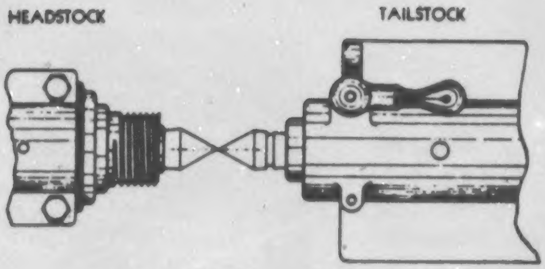
Figure 9-35.—Examples of center holes.



NO. OF COMB. DRILL AND COUNTERSINK	DIA. OF WORK W	LARGE DIAMETER OF COUNTERSUNK HOLE(C	DIA. OF DRILL D	DIA. OF BODY F
1	3/16" TO 5/16"	1/8"	1/16"	13/64"
2	3/8" TO 1"	3/16"	3/32"	3/16"
3	1 1/4" TO 2"	1/4"	1/8"	3/16"
4	2 1/4" TO 4"	5/16"	5/32"	7/16"

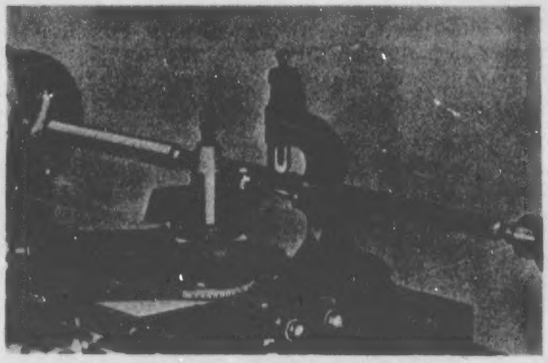
28.113X

Figure 9-36.—Correct size of center holes.



28.106

Figure 9-37.—Aligning lathe centers.



28.127X

Figure 9-38.—Follower rest supporting work turned between centers.

will produce a taper rather than a consistent diameter.

Notice the setup in figure 9-38. A lathe dog is clamped to the shaft near the headstock. A projection on the dog rests in a slot in the faceplate, thereby turning the shaft. Also notice that a follower rest is used to prevent the shaft from springing away from the cutting tool.

Before turning accurate work, you should test the mandrel on centers before placing any work on it. The best test for runout is made with an indicator. The indicator is mounted on the toolpost and applied to the mandrel as it is turned slowly between centers. Any runout will then be registered on the dial which is graduated in thousandths of an inch. If there is runout and you cannot correct it by cleaning the live center and headstock spindle, the mandrel itself is at fault (assuming that the lathe centers are true) and cannot be used. The countersunk holes may have been damaged, or the mandrel may have been bent by careless handling. Be sure to always protect the ends of the mandrel when pressing or driving it into the work.

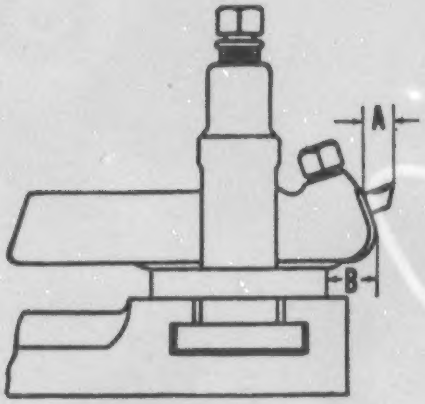
When taking roughing cuts on a piece of work mounted on a mandrel, you must have a tighter press fit than for finishing. Therefore, you should remove thin walled metal from the mandrel after the roughing cut and reload it lightly on the mandrel before taking the finish cut.

Setting the Cutting Tool

The first requirement for setting the tool is to have it rigidly mounted. Be sure the tool sets squarely in the toolpost and that the setscrew is tight. Reduce overhang as much as possible to prevent springing when cutting. If the tool has too much spring, the point of the tool will catch in the work causing chatter and damage to both the tool and the work. The distances represented by A and B in figure 9-39 show the correct overhang for the tool bit and the holder.

The point of the tool must be correctly positioned on the work. Place the cutting edge slightly above the center for straight turning of steel and cast iron, and exactly on the center for all other work and metals. To set the tool at the height desired, position the rocker under the toolholder. By placing the tool point opposite the tailstock center point, you can adjust the setting accurately.

If you are unaware of the meaning of the word "chatter," you will learn all too soon while working with a machine tool of any description. Briefly, chatter is vibration, in either the tool or the work, which causes a grooved or lined finish instead of the smooth surface that is to be expected. The vibration is set up by a weakness in the work, work support, tool, or tool support and is about the hardest thing to find in the entire field of machine work. As a general rule, strengthening the various parts of the tool support train will help, or you may need to regrind the tool bit. Also, you should support the work with a center rest or follower rest.



28.110X

Figure 9-39.—Tool overhang.

Machine adjustments may be the cause of chatter. Gibs may be too loose or bearings may be worn after a long period of heavy service. If the machine is in perfect condition, the fault will be in the tool or tool setup. Grind the tool nose to a smaller radius and avoid a wide, round leading edge on the tool. See that the work receives proper support for the cut, and, above all, do not try to turn at a surface speed that is too high. Excessive speed is probably the greatest cause of chatter, and the first thing you should correct when chatter occurs.

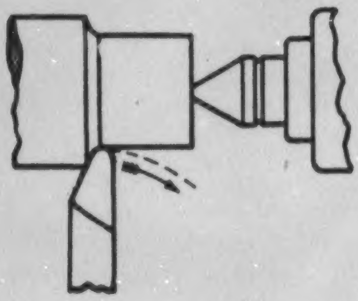
Turning

Turning is the machining of excess stock from the periphery of the workpiece to reduce the diameter. In most machining operations that require removal of large amounts of stock, a series of roughing cuts is taken to remove most of the excess stock; then a finishing cut is taken to accurately "size" the workpiece. The proper tool should be selected for taking a heavy cut. The speed of the work and the amount of feed of the tool should be as great as the tool will stand.

When taking a roughing cut on steel, cast iron or any other metal that has a scale upon its surface, be sure to set the tool deep enough to get under the scale in the first cut. Unless you do, the scale on the metal will dull the point of the tool.

Figure 9-40 shows the position of the tool for taking a heavy cut on large work. The tool should be set so that if anything occurs during machining to change the position of the tool, it will not dig into the work, but will move in the direction of the arrow—away from the work. Setting the tool in this position sometimes prevents chatter.

Regardless of how the work is held in the lathe, the tool should feed toward the headstock. In this way most of the pressure of the cut will be exerted on the workholding device and spindle thrust bearings. When it is



28.132X

Figure 9-40.—Position of tool for heavy cut.

necessary to feed the cutting tool toward the tailstock, take lighter cuts at reduced feeds.

The work should be rough machined to almost the finished size; then be careful in measuring.

Bear in mind that the diameter of the work being turned is reduced by an amount equal to twice the depth of the cut; thus, if you want to reduce the diameter of a piece by .010 inch, you must remove .005 inch from the surface.

When the work has been rough turned to within about 1/32 inch of the finished size, take a finishing cut. A fine feed, the proper lubricant, and above all a keen-edged tool are necessary to produce a smooth finish. Measure carefully to be sure that you are machining the work to the proper dimension. Stop the lathe when measuring.

Where very close limits are to be held, be sure that the work is not hot when you take the finish cut. Cooling of the piece will leave it undersized if it was turned to the exact size while hot.

Perhaps the most difficult operation for a beginner in machine work is to make accurate measurements. So much depends on the accuracy of the work that you should make every effort to become proficient in the use of measuring instruments. A certain "feel" in the use of micrometers is developed through experience alone; do not be discouraged if your first efforts do not produce perfect results. Practice taking micrometer measurements on pieces of known dimensions. You will acquire skill if you are persistent.

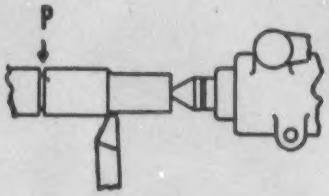
Machining to a shoulder is often done by locating the shoulder with a parting tool as shown at "P" in figure 9-41. Insert the parting tool about 1/32 inch from the shoulder line, and enter the work to within 1/32 inch of the finished diameter of the work. Then machine the stock by taking heavy cuts up to the shoulder thus made. Shouldering eliminates repeated measuring and speeds up production. Then you can take a finishing cut to accurate measurement.

Facing

Facing is the machining of the end surfaces and shoulders of a workpiece. In addition to squaring the ends of the work, facing provides a means of accurately cutting the work to length. Generally, in facing the workpiece, only light cuts are needed as the work will have been cut to approximate length or rough machined to the shoulder.

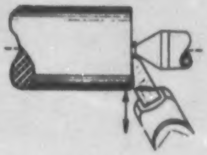
Figure 9-42 shows the methods of facing the end of a shaft. A right-hand tool is used as shown, and a light cut is taken on the end of the work, feeding the tool (by hand or power crossfeed) from the center toward the outside. One or two cuts are taken to remove sufficient stock to true the work.

Figure 9-43 shows the application of a turning tool in finishing a shouldered job that



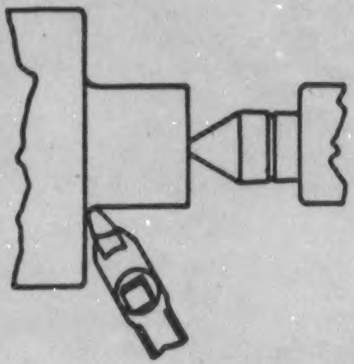
28.133X

Figure 9-41.—Machining to a shoulder.



28.129X

Figure 9-42.—Facing the end of a shaft.



28.130X

Figure 9-43.–Facing a shoulder.

has a fillet corner. A finish cut is taken on the small diameter, and the fillet is machined with a light cut. Then the tool is used to face from the fillet to the outside diameter of the work.

In facing large surfaces the carriage should be locked in position, since only crossfeed is needed to transverse the tool across the work. With the compound rest set at 90° (parallel to the axis of the lathe), the micrometer collar can be used to feed the tool to the proper depth of cut in the face. For greater accuracy in obtaining a given size in finishing a face, the compound rest may be set at 30°. In this position, one-thousandth of an inch movement of the compound rest will move the tool exactly one-half of a thousandth of an inch into the work. (In a 30°-60° right triangle, the length of the side opposite the 30° angle is equal to one-half the length of the hypotenuse.)

Boring

Boring is the same as turning, except that cuts are taken from the inside surface of the work. If the outside surface is running true, a bored hole will be perfectly concentric. Stock to be bored can be held in a chuck or collet, and long pieces should be supported with a center rest.

Figure 9-44 shows a boring bar and holder with insert type tool bits used in the boring bar, as well as the application of the boring bar for internal threading and boring. If the hole does not go through the work, set the tool bit as shown so you can face off the bottom of the hole to proper depth.

28.135

Figure 9-44.–Application of boring bar holder.

In most boring setups, you will need to drill a hole in the workpiece to provide clearance for the boring bar and tool bit. Start the hole with a center drill, then use as many drills of increasing size as necessary to approach the finished size desired. When drilling deep holes, use a coolant and completely withdraw the drill frequently to clear chips.

When a piece of work must be reamed to exact size and the correct drill is not available, boring is the only solution. Bore the work to within 1/64 inch of finished size, reduce speed by 50%, then use a coolant to ream the hole.

One problem you will encounter with boring is that most holes will be slightly tapered, especially deep holes. This is caused by "spring" in the boring bar. You can bore the hole true by taking a series of very light cuts as you near the finished size. You can also bore into the work, reverse feed, and take a cut coming out of the work without changing the depth of cut. However, you will need a specially ground tool for this operation or you may encounter chatter.

Tapering

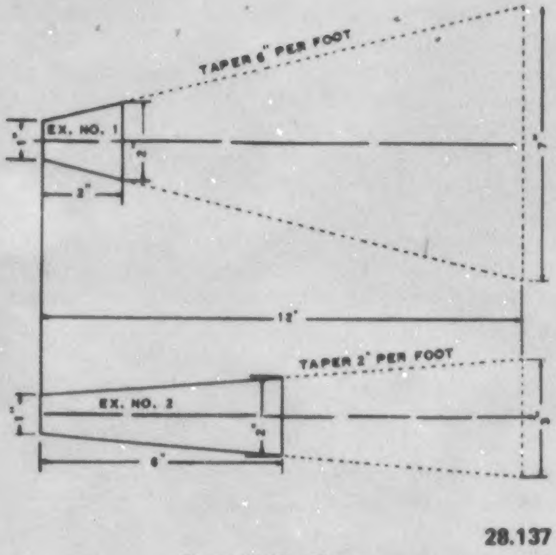
Taper is defined as the gradual reduction in diameter of an object toward one end. For machine operation, taper is expressed as the amount of change in diameter over 1 foot of length, regardless of the length of the object. The following formula applies:

$$\frac{Dl - Ds}{L} \text{ X } 12 = \text{taper per foot (TPF)}$$

Where: Dl is the larger diameter
Ds is the smaller diameter
L is the length

Example 1: Find the taper per foot of a piece 2 inches in diameter at the large end, 1 inch in diameter at the small end, and 2 inches long. (See figure 9-45.)

$$\frac{2 - 1}{2} \text{ X } 12 = \text{6-inch TPF}$$



28.137

Figure 9-45.—Tapers.

Example 2: Find the taper per foot of a piece 2 inches in diameter at the large end, 1 inch in diameter at the small end, and 6 inches long. (See figure 9-45.)

$$\frac{2 - 1}{6} \text{ X } 12 = \text{2-inch TPF}$$

In the foregoing examples, notice that the actual amount of taper in both pieces is 1 inch (difference in size of large and small ends), but the degree of taper in a certain length is important in establishing the TPF.

Tapers are also expressed as an angle. The included angle of a tapered piece is twice the angle that a cutting tool must make with the axis of a lathe to produce that taper. For instance, if you want to cut a 60° lathe center, you must set the compound rest at 30°.

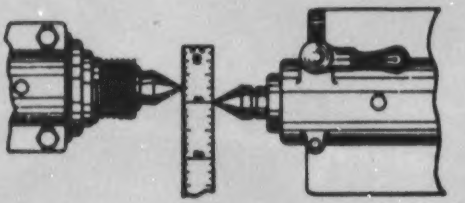
There are several standard tapers in common usage for machine tools. (Morse, Jarno, and Brown & Sharpe). This standard usage makes it possible to interchange parts and attachments. Taper pins have a 1/4-inch TPF and pipe threads have a 3/4-inch TPF.

If you are ever required to make a special fitting for a machine, simply refer to the *Machinist's Handbook* for all necessary dimensions.

To produce a taper, you must either cause the cutting tool to move at an angle in relation to the axis of the lathe (taper attachment-compound rest), or you must mount the work at an angle (tailstock setover).

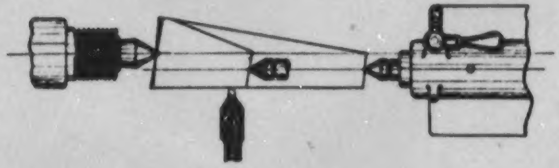
As stated earlier, adjusting screws allow you to move the tailstock top laterally on its base. In straight turning, you will recall that you used these adjusting screws to align the dead center with the live center by moving the tailstock to bring it on the centerline. In taper turning, you deliberately move the tailstock off center, and the amount you move it determines the taper produced. You can set the approximate amount of setover by using the zero lines inscribed on the base and top of the tailstock. Then, for final adjustment, measure the setover with a rule between center points, as illustrated in figure 9-46.

In turning a taper by this method, the distance between centers is of utmost importance. To illustrate, figure 9-47 shows two



28.140X

Figure 9-46.—Measuring setover of dead center.



28.141X

Figure 9-47.—Setover of tailstock showing importance of considering length of work.

very different tapers produced by the same amount of setover of the tailstock. The closer the dead center is to the live center, the steeper the taper produced. Tapers produced by this method are less accurate than by other methods because you cannot completely seat the centers in the center holes.

The compound rest is generally used for short, steep tapers. Such jobs are often referred to as working to an angle rather than as taper work. The length of taper that can be machined by this method is necessarily short because of limited travel of the compound rest.

The graduations marked on the compound rest allow you to set the angle you need quickly. When set at zero, the compound rest is perpendicular to the lathe axis. When set at 90° on either side, the compound rest is parallel to the lathe axis.

On the other hand, when the angle to be cut is measured from the centerline, the setting of the compound rest corresponds to the complement of that angle (the complement of an angle is that angle, which, when added to it, makes a right angle). For example, to machine a 50° included angle (25° angle with the centerline), set the compound rest at 90° - 25°, or 65°.

When you must make a very accurate setting of the compound rest to a fraction of a degree, run the carriage up to the chuck, and set the compound rest with a vernier bevel protractor set to the required angle. Hold the blade of the protractor on the flat surface of the chuck, and hold the base against the finished side of the compound rest.

For turning and boring long tapers with accuracy, the taper attachment is indispensable. It is especially useful in duplicating work; you can turn and bore identical tapers with one setting on the taper guide bar.

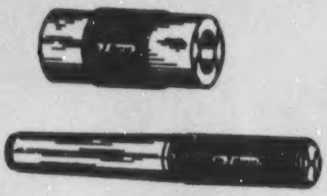
When preparing to use the taper attachment, position the carriage approximately in the middle of the length of the work to be tapered, and move the cutting tool nearly up to the work with the cross-slide handwheel. Set the desired taper on the guide bar. NOTE: You must set the tool bit exactly on center for taper turning.

Now remove the chip guard from the cross-slide and disengage the crossfeed nut (fig. 9-18). Position the taper guide bar even with the ends of the saddle and clamp the holding bracket to the ways (fig. 9-22). Attach the slotted guide to the cross-slide, then tighten the hand clamp on top. Lateral movement of the tool bit is now controlled by the taper attachment. Adjustments for depth of cut will be made with the compound rest.

Carefully eliminate any mechanical backlash in the setup for each cut you take by moving the carriage so the cutting tool goes past the end of the work prior to engaging longitudinal feed. If you neglect this step, a short section of the work will be turned straight, rather than tapered, until slack is taken up.

In making a blind tapered hole, such as may be required in drill sockets, it is best to drill the hole carefully to the correct depth with a drill of the same size as specified for the small end of the hole. This gives the advantage of boring to the right size without having to remove metal at the extreme bottom of the bore, which is rather difficult, particularly in small, deep holes.

Precision plug and socket gages (fig. 9-48) are used to test the size and accuracy of standard tapers. For nonstandard tapers, the mating part is used. After taking several cuts, remove chips from the work and make a chalk mark the full length of the male taper. Then fit



28.144X

Figure 9-48.—Morse taper socket gage and plug gage.

the parts together and twist slightly to mark the chalk. If the parts do not bear evenly the full length of the chalk mark, you must make a slight adjustment on the taper guide bar. Take another cut, chalk and fit the parts, and make another adjustment until the taper is correct before turning to required size.

Threading

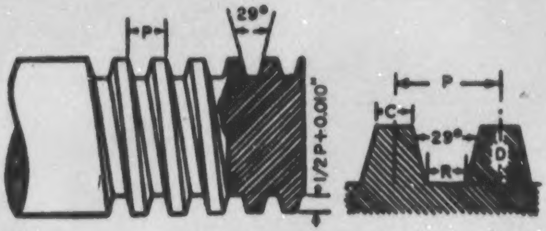
Most of the machine work done by an Opticalman is limited to V-form threads, even though normal duties will bring you in contact with acme threads (fig. 9-49) and square threads (fig. 9-50).

Each of these thread forms is used for specific applications. V-form threads are commonly used on fastening devices such as bolts and nuts as well as on machine parts. Acme screw threads are generally used for transmitting motion such as that between the lead screw and lathe carriage. Square threads are used to increase mechanical advantage and to provide good clamping ability as in the screw jack or vise screw.

There are many terms used in describing screw threads and screw thread systems which you must know before you can calculate and machine screw threads. Figure 9-51 illustrates the application of some of the following terms:

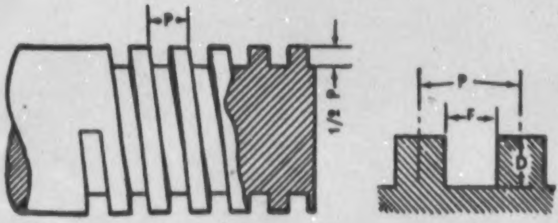
EXTERNAL THREAD: A thread on the external surface of a hollow cylinder.

INTERNAL THREAD: A thread on the internal surface of a hollow cylinder.



28.147X

Figure 9-49.—Acme thread.



28.149X

Figure 9-50.—Square thread.

RIGHT-HAND THREAD: A thread which, when viewed axially, winds in a clockwise and receding direction.

LEFT-HAND THREAD: A thread which, when viewed axially, winds in a counterclockwise and receding direction.

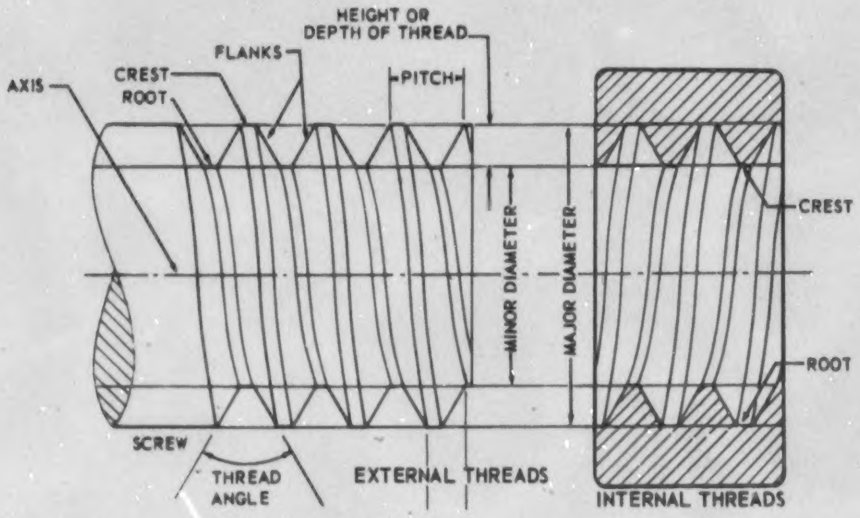
LEAD: The distance a threaded part moves in one complete revolution.

PITCH: The distance between corresponding points on adjacent threads.

SINGLE THREAD: A single (single start) thread which has a lead equal to the pitch.

MULTIPLE THREAD: A multiple (multiple start) thread has a lead which is equal to the pitch multipied by the number of starts.

CLASS OF THREADS: Classes of threads are distinguished from each other by the amount of clearance between mating parts (nut and bolt). A 1/2-inch bolt with 13 threads could be a shrink fit (class 5) through a loose fit (class 1).



28.145

Figure 9-51.–Screw thread nomenclature.

THREAD FORM: The cross section profile of a thread.

FLANK: The side of the thread.

MAJOR DIAMETER: The diameter of a cylinder that bounds the crest of an external thread or the root of an internal thread.

MINOR DIAMETER: The diameter of a cylinder that bounds the root of an external thread or the crest of an internal thread.

CREST: The top of the thread (bounded by the major diameter on external threads; by the minor diameter on internal threads).

ROOT: The bottom of the thread (bounded by the minor diameter on external threads; by the major diameter on internal threads).

THREAD ANGLE: The angle formed by adjacent flanks of a thread.

HEIGHT OF THREAD: The distance from the crest to the root of a thread measured perpendicular to the axis of the threaded piece (also called depth of thread).

SLANT DEPTH: The distance from the crest to the root of a thread measured along the flank of the thread.

THREAD SERIES: Groups of diameter/pitch combinations which are distinguished from each other by the number of threads per inch to a specific diameter. The common thread series are the coarse series and the fine series (1/4-20nc-1/4-28nf).

The Naval Sea Systems Command and naval procurement activities use American Standard Unified threading systems whenever possible; this system is recommended for use by all naval activities. The American Standard thread is a unified series of threads which permits the U.S. to interchange standard thread fastening devices manufactured in the United States, Canada, and the United Kingdom.

V-FORM SCREW THREAD.–To cut a V-form thread, you need to know (1) the pitch of the thread, (2) the straight depth of the thread, (3) the slant depth of the thread, and (4) the width of the flat at the root of the thread.

Pitch.–The pitch of a thread is the basis for calculating all other dimensions and is equal to 1 divided by the number of threads per inch.

Straight Depth.–Twice the straight depth of an internal thread subtracted from the outside diameter of the externally threaded part determines the bore diameter of a mating part to be threaded internally.

Slant Depth.–When the thread-cutting tool is fed into the workpiece at one-half of the included angle of the thread, the slant depth determines how far to feed the tool into the work.

Width of the Flat.–The point of the threading tool must have a flat equal to the width of the flat at the root of the thread (external of internal thread, as applicable). If the flat at the point of the tool is too wide, the resulting thread will be too thin if the cutting tool is fed in the correct amount. If the flat is too narrow, the thread will be too thick.

The following formulas will provide you with the information you need to know for cutting V-form American Standard Unified Threads.

Pitch = 1 ÷ number of threads per inch, or $\frac{1}{n}$

Depth of external thread = 0.61343 X pitch

Depth of internal thread = 0.54127 X pitch

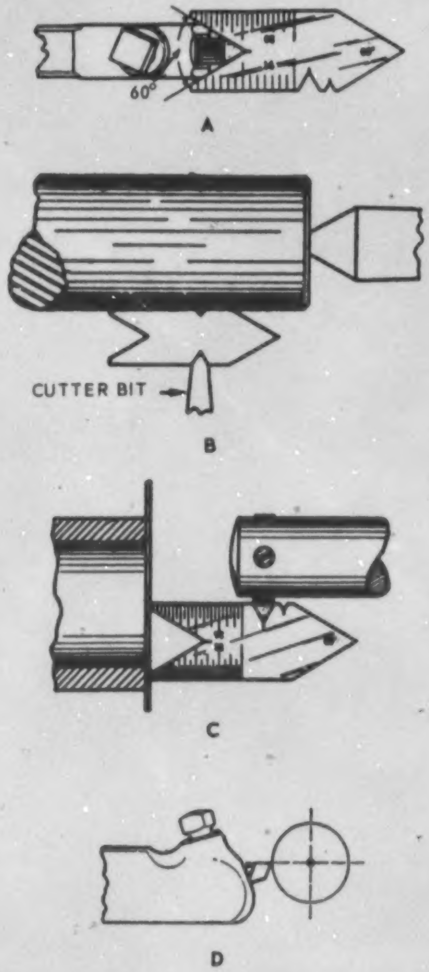
Width of flat at point of tool for external threads = 0.166 X pitch

Width of flat at point of tool for internal threads = 0.125 X pitch

Slant depth of external thread = 0.708 X pitch

Slant depth of internal thread = 0.625 X pitch

To produce the correct thread profile, the cutting tool must be accurately ground to 60° with 0° back rake (fig. 9-52A). Also the cutting tool must be set in the correct position.



28.146X

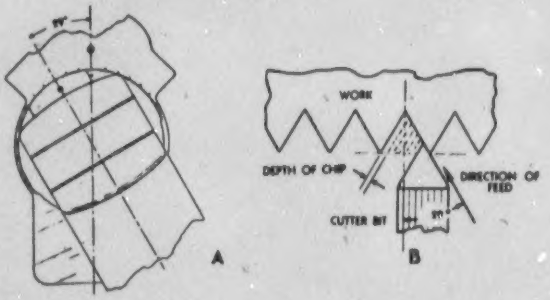
Figure 9-52.–Threading tool setup for V-form threads.

Use a center gage or a thread-tool gage to check the exact angle. The top of the tool is usually ground flat. However, for cutting threads in steel, side rake is sometimes used.

Set the threading tool square with the work, as shown in B and C of figure 9-52. Use the center gage to position the point of the threading tool. Of course, if you do not set the threading tool perfectly square with the work, the angle of the thread will be incorrect.

For cutting external or internal threads, place the top of the threading tool exactly on center as shown in D of figure 9-52. Note that the top of the tool is ground flat and is in exact alignment with the lathe center.

Size of the threading tool for cutting an internal thread is important. The tool head must be small enough to be backed out of the thread and still leave enough clearance to be drawn from the threaded hole without injuring the thread. However, the boring bar which holds the threading tool for internal threading should be both as large as possible in diameter and as short as possible to prevent its springing away from the work during cutting.



28.150X

Figure 9-53.—Compound rest set at 29°.

USING A LATHE FOR CUTTING THREADS.—For cutting screw threads, the headstock spindle of the lathe is connected to the lead screw by a series of gears to obtain a positive carriage feed; the lead screw is driven at the required speed with relation to the headstock spindle. The gearing between the headstock spindle and lead screw can be arranged to cut any desired pitch. For example, if the lead screw has 8 threads per inch and the gears are arranged so that the headstock spindle revolves four times while the lead screw revolves once, the thread cut will be four times as fine as the thread on the lead screw, or 32 threads per inch. The quick-change gear box allows you to make the proper gearing arrangement quickly and easily by placing the levers, as indicated on the index plate, for the thread desired.

Until you become very proficient at threading, always put the lathe in back gear and turn the headstock at approximately 60 rpm.

When threading work in the lathe, be sure the chuck jaws are tight and the work is well supported. Never remove the work from the chuck until the thread is finished.

When threading long slender shafts, use a follower rest. Use the center rest to support one end of long work that you are threading on the inside.

To cut external V-form threads, it is customary to place the compound rest of the lathe at an angle of 29°, as shown in part A of figure 9-53. With the compound rest set in this position and the compound rest screw adjusted to the depth of cut, most of the metal will be removed by the left side of the threading tool (B of fig. 9-53). The chip will curl out of the way better than if the tool is fed straight in. Also, the thread will not tear. Since the angle on the side of the threading tool is 30°, the right side of the tool will shave the thread smooth and produce a better finish, although it does not remove enough metal to interfere with the main chip.

To cut internal V-form threads, set the compound rest at 29° in the opposite direction and back the tool into the work for each cut.

To prepare for the first threading cut, position the carriage so you can feed the tool in with the cross-slide handwheel to contact the work. Then, loosen the locks on the cross-slide and compound rest micrometer collars and set the collars to zero. Be sure to tighten the micrometer collar lock screws. Move the carriage so the threading tool is approximately 1/2 inch from the end of the work.

To cut threads on a lathe, clamp the half-nuts (threading lever) over the lead screw to engage the threading feed. At the end of the cut release the threading feed with the threading lever. Use the threading dial (fig. 9-25), discussed earlier in this chapter, to determine the time to engage the threading lever so that the cutting tool follows the same path during each cut. Align the index mark on the threading dial with the witness mark on the housing, then engage the threading lever. For some thread pitches, however, the threading lever can be engaged only when certain index marks are aligned with the witness mark. You can engage the threading lever on most lathes as follows:

1. For all even-numbered threads per inch, close the threading lever at any line on the dial.

2. For all odd-numbered threads per inch, close the threading lever at any numbered line on the dial.

3. For all threads involving one-half of a thread in each inch, such as 11 1/2, close the threading lever at any odd-numbered line.

With the lathe set up as previously explained, you are now ready to take a very light trial cut. Start the lathe, watch the threading dial, and engage the threading lever. When the threading tool comes to the end of the length of thread desired, you must do two things at once: (1) Disengage the threading lever, and (2) back the crossfeed out one revolution. This is particularly important in threading to a shoulder or the bottom of a hole.

Now stop the lathe and check the thread produced with a screw pitch gage. The gage consists of a number of sheet metal plates in which are cut the exact form of threads of the various pitches. Each plate is stamped with the number of threads per inch for which it is to be used.

Compare the appropriate gage with the thread you just cut to be sure you have the quick change gear box set properly.

If the thread is correct, proceed with the threading. Move the carriage past the start of the work, return the crossfeed to zero, feed the compound rest in a few thousandths, and take another cut. NOTE: Always use the correct cutting lubricant when threading.

You do not have to stop the lathe after each cut. After you disengage the threading lever and back out the crossfeed, move the carriage past start, reset the crossfeed, feed the compound rest a few more thousandths, apply lubricant, and continue until you reach the predetermined depth for your thread.

Make the final check for fit, using the mating part for which you are machining the thread. You will usually want a snug fit without binding. If the thread is too tight take another light cut. If the fit is too loose, you have made some incorrect calculations or adjustments and have wasted time and material. Do not be discouraged if your first attempts at threading are not perfect. Just do not make the same mistakes again.

If the threading tool must be sharpened during operation or if you are chasing a previously cut thread, you can reset the lathe to catch the thread in the following manner.

Use a center gage to check the angle of the tool and to set the tool square with the work. Also be sure the tool is again on center. Then with the tool a few thousandths of an inch away from the workpiece, start the machine and engage the threading mechanism; then stop the lathe.

Adjust the compound rest slide forward or backward so that the tool moves along the axis of the work as well as toward or away from the work. When the point of the tool coincides with the original thread groove, use the crossfeed screw to bring the tool point directly into the groove. When you get a good fit between the cutting tool and thread groove, set the micrometer collar on the crossfeed screw on zero. Set the micrometer collar on the compound rest feed screw to the depth of cut previously taken or to zero, as required. Now back the cross-slide out, move the carriage past the start of the thread, and proceed with the cutting.

SAFETY PRECAUTIONS

You have studied the lathe and its operating procedures, but before you can apply this knowledge, you must understand and observe the principles of safety. Thought, guided by common sense, is the surest safeguard against accidents.

Moving machinery is always a danger, and when associated with a sharp cutting tool, the hazard greatly increases. Treat a machine with respect and there will be no need to fear it.

When operating a lathe or any machine tool, be sure that the area is free of personnel and objects that could make the job more hazardous. Your responsibility, as the operator, is to look out for others as well as yourself when chips are flying and your machine is in motion.

Safety precautions for all machinery in the shop are posted in the work area, so never begin an operation without reading these precautions. The posted precautions give detailed instructions that apply to the machine you are operating. In this chapter we can list only the general safety rules that apply.

1. Always protect your eyes and your limbs from chips and moving parts by wearing safety goggles. Do not wear any loose clothing that can get caught in revolving parts.

2. Never attempt to clean, repair, or adjust a moving machine.

3. Before starting a machine, ensure that chuck keys and loose tools have been removed from the machine.

4. Be sure that all gear covers and safety guards are in place.

5. Never lean against a moving machine or attempt to stop a moving machine by any means other than the proper control levers.

THE MOST IMPORTANT THING THAT AN OPERATOR CAN LEARN ABOUT A LATHE OR ANY OTHER MACHINE TOOL IS THE SAFETY PRECAUTIONS.

MILLING MACHINES

A milling machine removes metal with a revolving cutting tool called a milling cutter. With various attachments, milling machines can be used for boring, broaching, circular milling, dividing, and drilling; for cutting keyways, racks, and gears; and for fluting taps and reamers.

To advance in rating you must demonstrate the ability to set up and perform basic operations using the milling machine. To set up and operate a milling machine, you must compute feeds and speeds, select and mount the proper holding device, and select and mount the proper cutter to handle the job.

Like other machines in the shop, milling machines have both manual and power feed systems, a selective spindle speed range, and a coolant system.

KNEE AND COLUMN TYPE

The knee and column type milling machine is the most commonly used by the Navy. Because of its ease of setup and its versatility, this machine is more efficient than other types. The main casting consists of an upright column, to which is fastened a bracket, or "knee," which supports the table. The knee can be adjusted to raise or lower the table to accommodate various sized pieces of work.

You can take vertical cuts by feeding the table up or down. You can move the table in the horizontal plane in two directions: either at right angles to the axis of the spindle or parallel to the axis of the spindle. Therefore, you can mount work at practically any location on the table.

Knee and column milling machines are made in three designs; plain, universal, and vertical spindle.

Plain Milling Machine

As in all milling machines of this type, you can move the table of the plain milling machine in three directions: longitudinal (at right angles to the spindle), transverse (parallel to the spindle), and vertical (up and down). The machine's chief value results from its rigid construction–it can take heavy cuts at fast speeds with coarse feeds.

Universal Milling Machine

The universal milling machine (fig. 9-54) has all the principal features of the other types of milling machines. It can handle practically all classes of milling work. Its main advantage over the plain mill is that you can swivel the table on the saddle so that it moves at an angle to the spindle on a horizontal plane. This machine is used to cut most types of gears, milling cutters, and twist drills and is used for various kinds of straight and taper work.

28.197X

Figure 9-54.—Universal milling machine.

A vertical milling attachment can be mounted in place of the overarms so that the spindle is vertical, rather than horizontal as shown. The basic design of the universal mill, coupled with a variety of attachments, makes this the most versatile of all milling machines.

Vertical Spindle Milling Machine

The vertical spindle milling machine (fig. 9-55) has the spindle in a vertical position and is similar in design and operation to the plain and universal milling machines. The vertical spindle can also be positioned up to 90° left or right of vertical. Since you can see both the cutter and the surface being cut, you can do face milling and end milling more easily on the vertical spindle milling machine than on mills of other types.

Vertical spindle mills embody the principles of the drill press. The spindle and table both have a vertical movement, and the table also has longitudinal and transverse movement. You can use this type of machine for face milling, profiling, and die sinking, and various odd-shaped jobs; you can also use it for boring holes.

Although knee and column milling machines vary slightly in design, depending on the manufacturer, the components labeled in figure 9-54 are common to most milling machines.

The spindle nose of all milling machines has a standard internal taper. Driving keys, or lugs, on the face of the spindle nose drive the cutter directly, or drive an arbor or adapter on which the cutter is mounted (fig. 9-56). The overarms, yokes, and overarm supports are used for accurate alignment and to support arbors. You can retract or extend the overarms from the column to any length needed to support the arbor. The overarm supports are extremely helpful in supporting the cutter for taking heavy cuts. The overarm supports are used with the yokes and overarms.

STANDARD EQUIPMENT

Standard equipment for milling machines in Navy ships includes work-holding devices, spindle attachments, cutters and arbors, and any special tools needed for setting up the machine for milling. This equipment permits holding and cutting the great variety of milling jobs found in Navy repair work.

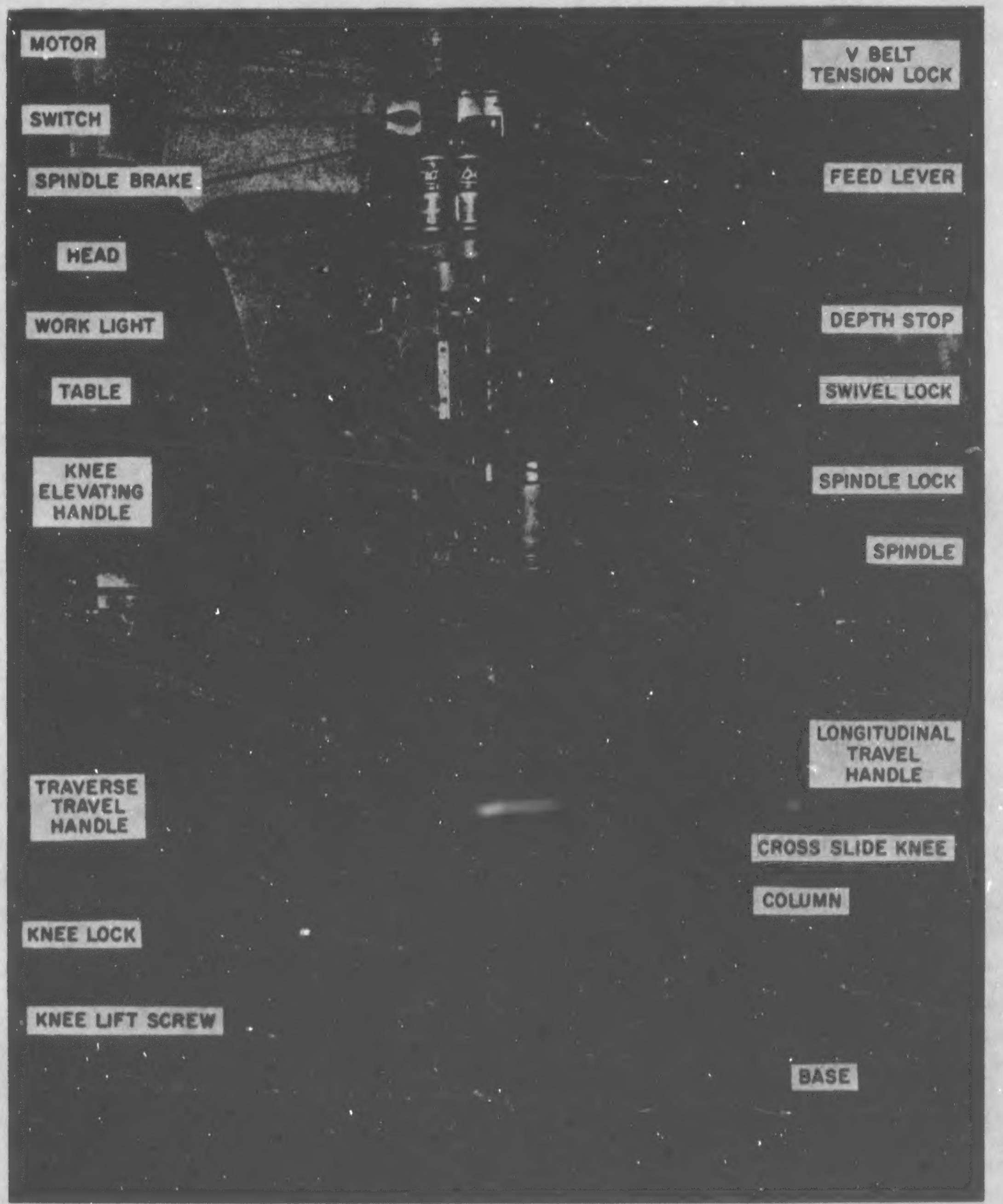
Vises

The vises commonly used on milling machines are the flanged plain vise, the swivel vise, and the toolmakers universal vise (fig. 9-57).

A flanged vise provides a rigid work-holding setup when the surface to be machined must be parallel to the surface seated in the vise.

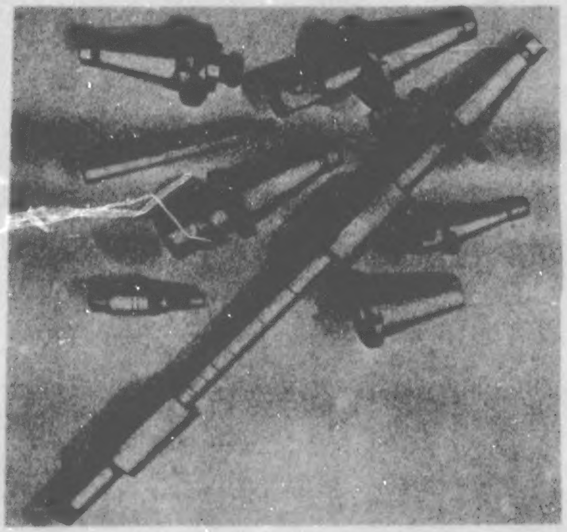
A swivel vise is used similarly to a flanged vise, but the setup is less rigid, allowing the workpiece to be swiveled in a horizontal plane to any required angle.

A toolmakers universal vise is used when the workpiece must be set up at a complex angle in relation to the axis of the spindle and to the table surface.



28.198(28D)

Figure 9-55.—Small vertical spindle milling machine.



28.204X
Figure 9-56.—Arbors, sleeves, and special adapters.

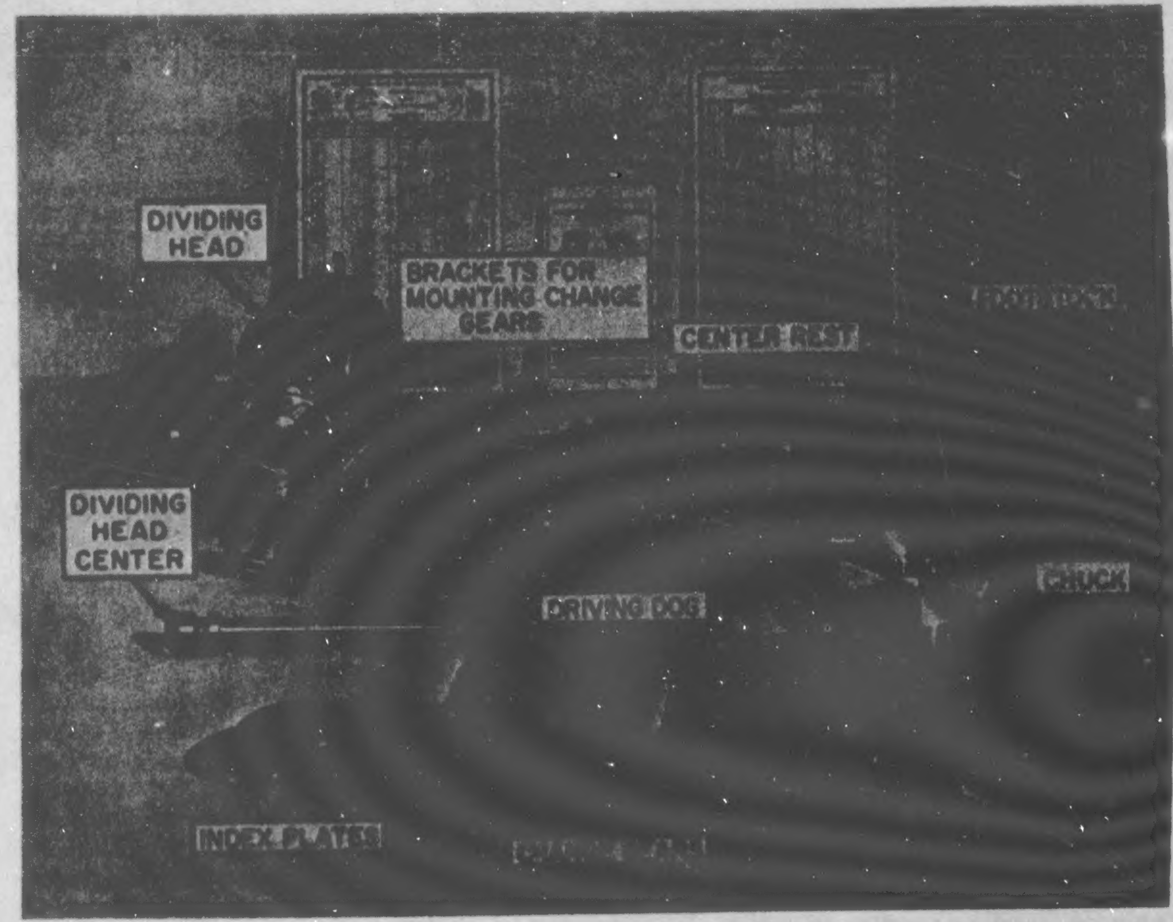
28.199X
Figure 9-57.—Milling machine vises.

Index Head

Indexing equipment (fig. 9-58) is used for holding and turning the workpiece to make a number of accurately spaced cuts (gear teeth, for example). The workpiece is held in a chuck, attached to the index head spindle. The center rest can be used to support long slender work. The center of the footstock may be raised or lowered to set up tapered workpieces.

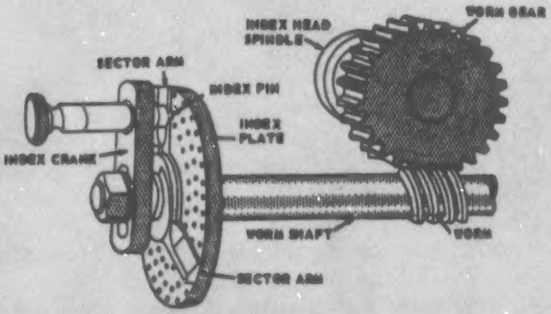
The basic components of an index head are shown in figure 9-59. The ratio between the worm and gear is 40 to 1. One turn of the worm rotates the spindle 1/40 of a revolution. The index plates, which have a series of concentric circles of holes, permit accurate gaging of partial turns of the worm shaft and allow the spindle to be turned accurately in amounts smaller than 1/40 of a revolution. It is also easy to convert spindle rotation to an angular value in degrees and minutes. The index plate may be secured to the index head housing or to the worm shaft. You can adjust the crankpin radially for use in any circle of holes. You can set the sector arms to span any number of holes in the index plate to provide a guide for rotating the index crank for partial turns.

You can turn the index head spindle by hand, by the index crank through the worm and worm gear, or by the table feed mechanism through a gear train. The first two methods are



28.200X

Figure 9-58.—Index head and associated fittings.



28.201

Figure 9-59.—Index head mechanism.

for indexing, while the third is for rotating the workpiece (while it is being cut) to make helical cuts.

Universal Milling Attachment

The universal milling (head) attachment (fig. 9-60) is clamped to the column of the milling machine. The cutter can be secured in the spindle of the attachment and set by two rotary swivels so that it will cut at any angle to the horizontal or the vertical plane. The spindle of the attachment is driven by gearing connected to the milling machine spindle.

28.202X

Figure 9-60.—Circular milling attachment and universal (head) attachment.

Circular Milling Attachment

The circular milling attachment, or rotary table, shown in figure 9-60, is used to set up work which must be rotated in a horizontal plane. The worktable is graduated (1/2° to 360°) around its circumference. You can turn the table by hand or by the table feed mechanism through a gear train. An 80 to 1 worm and gear drive in the rotary table and index plate arrangement makes this device useful for accurate indexing of horizontal surfaces.

Milling Cutters

The variety of cutters used with milling machines adds to the versatility of the mill. Figure 9-61 shows a small sample of cutters commonly used. The cutters, used with other attachments, provide an endless list of applications.

End mills are used for facing, slotting, boring, and cutting various angles on work. Formed cutters (2 and 10) are used for cutting gears and racks. The other cutters shown are used for slitting, heavy facing or slotting, and for heavy slab cuts.

End mills are held in the milling machine spindle either in collets or special adapters. The other cutters are mounted on an arbor (fig.9-62) and are usually prevented from turning on the arbor by a key and keyway. You can mount a single cutter on the arbor, as shown, or you can mount several cutters and spacers to take multiple cuts with one setup.

Figure 9-63 shows how a dovetail or T-slot for holddown bolts is cut. First, rough out the hole with an end mill, then use the appropriate formed cutter. In fact, with a milling machine, if you ever need a specially shaped cutter you can make it yourself.

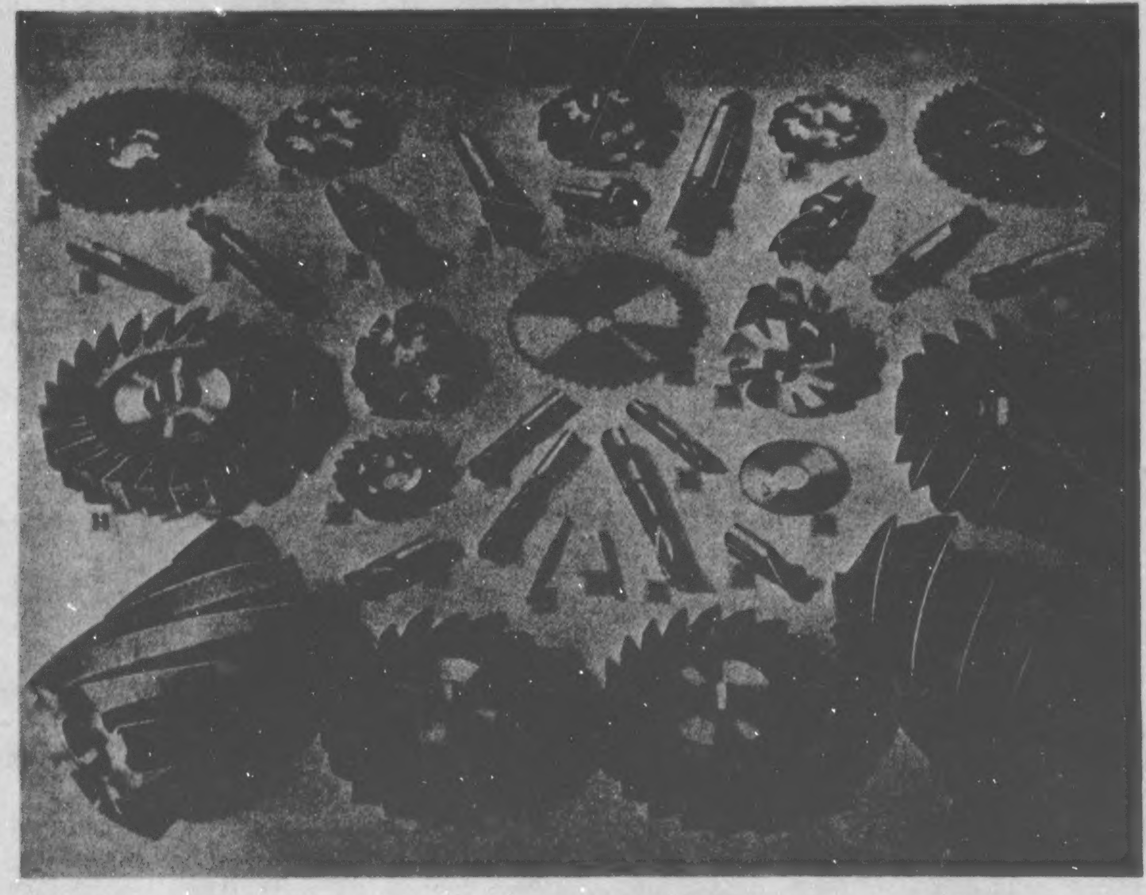
A word of caution concerning end mills. You can use two-lip end mills carefully to bore holes since the cutting edge extends the full width of the end (#8 in fig. 9-61). Four-lip mill ends are relieved in the center so only the outer half of each lip can cut (#11 in fig. 9-61). Do NOT use a four-lip end mill for boring; it could shatter, causing serious injuries.

As a general rule, the more teeth a cutter has, the smoother the finished surface will be. Helical teeth will also produce a very smooth cut. Coarse cutters and stagger-tooth cutters are normally used for roughing cuts. The distance between teeth allows ample room for chip clearance and coolant flow so heavy feeds can be used efficiently.

MILLING MACHINE OPERATION

A mill is more complicated to operate than a lathe, mainly because of the various attachments, applications, and planes of movement available. If you plan your work carefully, appreciate the limitations of the machine, and use reasonable caution, no one will get hurt, and the job should be successful.

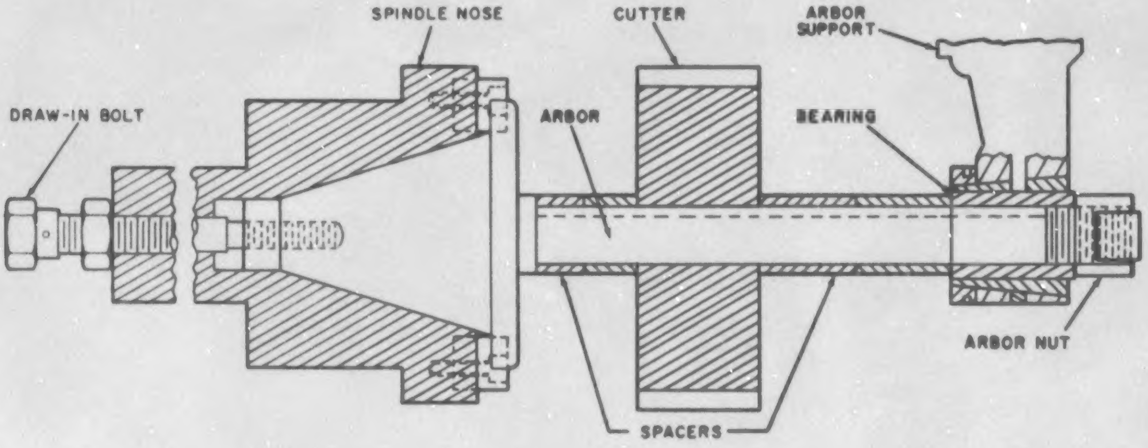
You must become thoroughly familiar with the controls for table feeds. Since the table moves in six directions, engaging the wrong lever could be disastrous.



1. Metal slitting saw
2. Involute spur gear cutter (undercut teeth)
3. Spiral end mill, taper shank
4. Two-lipped spiral mill, taper shank
5. Metal staggered-tooth slitting saw
6. Long two-lipped end mill, single end
7. Long spiral end mills, double end
8. Two-lipped spiral end mill, cam-locking
9. Corner rounding cutter
10. Involute form cutter
11. Four-lipped spiral end mill, cam-locking
12. Long two-lipped spiral end mill, double end
13. Long spiral end mill, single end
14. Half side milling cutter
15. Convex cutter
16. Woodruff keyseat cutter
17. Metal slitting saw
18. Concave cutter
19. Ball end mills
20. Long single-end end mill
21. Double-end end mills
22. Two-lipped long single-end end mill
23. Screw slotting cutter
24. Two-lipped spiral end mill, straight shank
25. Angular cutter
26. Spiral end mill, straight shank
27. Plain heavy duty spiral milling cutter
28. Staggered-tooth side milling cutter
29. Side milling cutter
30. Helical plain milling cutter
31. Shell end mill for use with shell end mill arbor

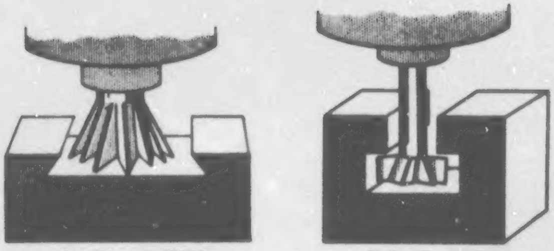
28.205X

Figure 9-61.—Milling machine cutters.



28.211

Figure 9-62.—Standard arbor.


DOVETAIL CUTTER

T-SLOT CUTTER

28.206X

Figure 9-63.—Application on T-slot and dovetail cutters.

Setup Procedures

Cutting tools and work holding devices must be TIGHT. With all components held securely, you avoid the possibility of vibration or of launching a piece of work across the shop. Mating surfaces must be absolutely clean and free of chips so that you can properly mount the work, cutter, and attachments.

A dial indicator is absolutely necessary for most setups. It is used (1) for squaring the table of a universal mill or the jaws of a swivel vise, (2) for trueing the spindle of a vertical mill or vertical attachment, (3) for checking runout of work held in an index head, and (4) for leveling other setups.

Once you are sure the cutter and work are properly mounted and are true and square, proceed with positioning the cutter. Figure 9-64 shows various methods for positioning cutters to mill round stock. These same methods are also used for all other shapes.

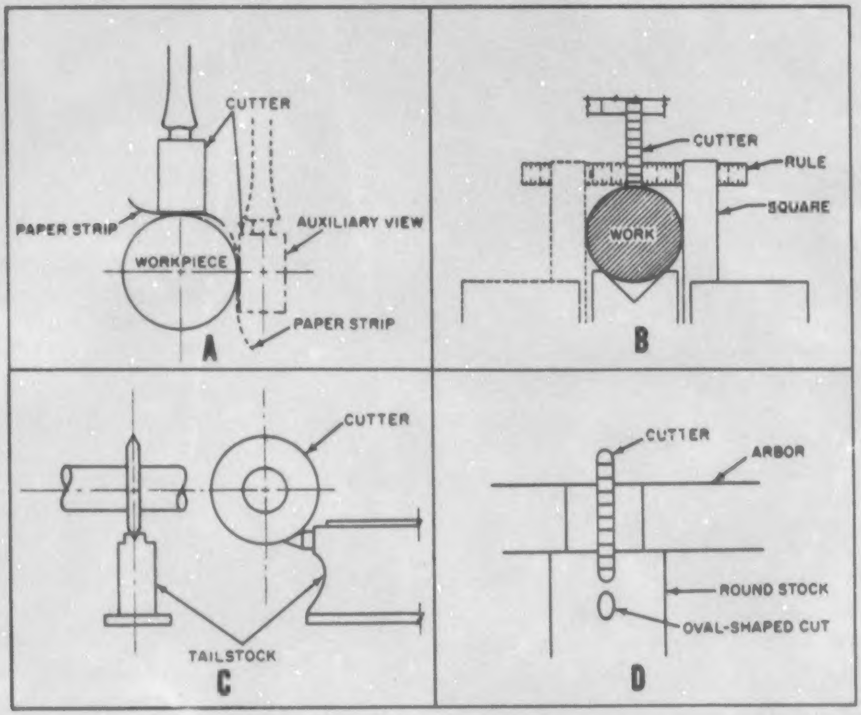
On a milling machine the crossfeed, longitudinal feed, and vertical feed handles have micrometer collars to allow very precise positioning.

The method shown in figure 9-64A is the most accurate method to position a cutter and should be used when possible.

1. Move the workpiece into position, as shown in the auxiliary view figure 9-64A, with the cutter about 0.010 inch away from the workpiece.

2. Insert a strip of paper (0.003 inch thick) between the cutter and the side of the workpiece and hold in place.

3. Start the cutter turning slowly and feed the workpiece toward the cutter until the cutter tears the paper strip; feed the table toward the cutter another 0.003 inch (thickness of the paper). The cutter will now be in very light contact with the side of the workpiece.



28.212

Figure 9-64.—Methods of positioning cutter.

NOTE: Be very careful to keep your hands clear of the cutter when using the paper.

4. If you intend to slot the top of the work, lower the table so that the cutter will clear the top of the workpiece.

5. Set the micrometer collar on the transverse feed handwheel to zero.

6. Move the worktable transversely by an amount equal to one-half the thickness of the cutter plus one-half the diameter of the workpiece. The cutter is now centered on the axis of the shaft.

The method just described works equally well with end mills or arbor type cutters.

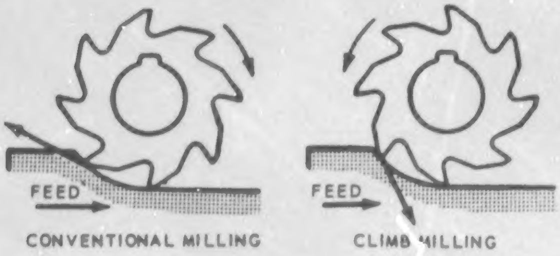
If the cutter is so small that the arbor or spindle nose touches the workpiece, you can align the cutter with some degree of accuracy by using squares on each side of the work and centering the cutter with a 6-inch rule (fig. 9-64B).

Figure 9-64C shows the method for aligning a cutter with the footstock center, if the work is to be held between centers.

Figure 9-64D shows a light trial cut taken with a perfectly centered cutter.

Direction of Cutter Rotation

In selecting the direction of cutter rotation and table travel, the conventional milling practice is to make the cutter revolve against the advancing table to cut up into the work (fig. 9-65). In milling deep slots or in cutting off thin stock with a metal slitting cutter, another system, known as the CLIMB MILLING process, is used. In this process you rotate the cutter with the direction of table feed, making the cutter cut down into the work. With the latter



28.213X

Figure 9-65.—Conventional and climb milling.

system there is less chance of the cutter being drawn to one side, producing crooked slots.

When the work moves with the cutter, you must carefully eliminate any looseness and lost motion in the table by setting the table gibs snugly. If you fail to eliminate looseness, the cutter teeth may draw the work in. The result may be a sprung arbor, a badly damaged cutter, a ruined piece of work, or serious personal injury.

Before you start any cutting, be sure the spindle is rotating in the proper direction. You will not remove much metal if the cutter is revolving backwards.

Feeds and Speeds

The spindle speed of milling machines usually ranges from 25 to 2,000 rpm, and the feed ranges from 1/4 inch to 30 inches per minute (ipm). Since the feed is independent of the spindle rotation, a workpiece can be fed at any rate in the feed range regardless of the spindle speed. Some of the factors concerning the selection of appropriate feeds and speeds for milling are discussed in the following paragraphs.

SPEEDS.—You can regulate the heat generated by friction between the cutter and work by using the proper speed, feed, and cutting coolant. Heat regulation is very important because the cutter will be dulled or even made useless by overheating. It is almost impossible to set down any fixed rules to govern cutting speeds because conditions vary from job to job. Generally speaking, you should select a cutting speed which gives the best compromise between maximum production and longest life of the cutter. In any particular operation, consider the following factors in determining the proper cutting speed:

- Hardness of the material being cut: The harder and tougher the metal being cut, the slower should be the cutting speed.

- Depth of cut and desired finish: The amount of friction heat produced is directly proportional to the amount of material being removed. Finishing cuts may often be made at a speed 40% to 80% higher than that used in roughing since the depth of cut is less.

- Cutter material: Carbide tooth cutters may be operated from 50% to 100% faster than high-speed steel cutters because carbide cutters have better heat resistant properties.

- Type of cutter teeth: Cutters with undercut teeth cut more freely than those with a radial face (gear cutters and concave and convex cutters); therefore, cutters with undercut teeth may be run at higher speeds.

- Sharpness of cutter: A sharp cutter may be run at a much higher speed than a dull cutter.

- Thickness of the cutter: Cutters like 27 and 30 in figure 9-61 put considerable strain on the machine; consequently, they should turn a little slower.

- Use of coolant: Sufficient coolant will usually cool the cutter so that it will not overheat even at relatively high speeds. The same coolants used for lathe work are appropriate for milling.

Use the approximate cutting speeds listed below as a guide in selecting the proper cutting speed for high-speed steel cutters. If you find that the machine, the cutter, or the work cannot be suitably operated at the suggested speed, make immediate readjustment. It is usually advisable to reduce the spindle speed and decrease the depth of cut.

	Rough (ft/min)	Finish (ft/min)
Cast iron:		
Malleable	90	100
Hard Castings	15	20
Annealed tool steel	40	50
Low Carbon steel	60	70
Brass	200	250
Aluminum	700	900

The proper cutting speed (fpm) for various diameter milling cutters turned at available spindle speeds (rpm) is:

$$\text{fpm} = \frac{\pi D \times \text{rpm}}{12}$$

This formula should be familiar to you by now, since you used it to compute drilling speeds and lathe cutting speeds.

Example: What spindle speed should you use to turn a 1/2-inch end mill to produce a cutting speed of 45 fpm?

$$45 \text{ fpm} = \frac{3.14 \times 0.5 \times \text{rpm}}{12}$$

or

$$540 = 1.57 \times \text{rpm}$$

$$\text{rpm} = \frac{540}{1.57} = 344$$

Example: What is the cutting speed of a 2 1/4-inch end mill turning at 204 rpm?

$$\text{fpm} = \frac{3.14 \times 2.25 \times 204}{12}$$

$$\text{fpm} = \frac{1441}{12} = 120$$

FEEDS.–The rate of feed is the rate at which the workpiece travels past the cutter. When selecting the feed, you should consider the following factors:

- Forces exerted against the work, the cutter, and their holding devices during the cutting process: The force exerted, varying directly with the amount of metal removed, can be regulated by the feed and depth of cut. The feed and depth of cut, therefore, are interrelated and in turn are dependent upon the rigidity and power of the machine. Machines are limited by the power they can develop to turn the cutter and by the amount of vibration they can withstand when coarse feeds and deep cuts are being used.

- The feed and depth of cut also depend upon the type of cutter being used. For example, deep cuts or coarse feeds should not be attempted with a small diameter end mill, as such an attempt will spring or break the cutter. Coarse cutters with strong cutting teeth can be fed at a relatively high rate of feed because the chips will be washed out easily by the cutting lubricant.

- Coarse feeds and deep cuts should not be used on a frail piece of work or on work mounted in such a way that the holding device will spring or bend.

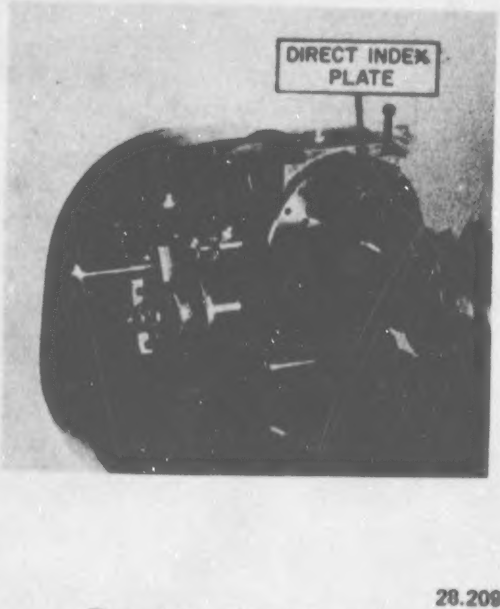
- The desired degree of finish affects the amount of feed. When a fast feed is used, metal is removed rapidly and the finish will not be very smooth. However, a slow feed rate and a high cutter speed will produce a finer finish. For roughing, you should use a comparatively low speed and a coarse feed. More mistakes are made by overspeeding the cutter than by overfeeding the work. Overspeeding produces a squeaking, scraping sound. If chatter occurs in the milling machine during the cutting process, reduce the speed and increase the feed. Excessive cutter clearance, poorly supported work, or a badly worn machine gear are also common causes of chattering.

Indexing

Direct indexing, sometimes called rapid indexing, is done with the 24-hole direct index plate which is mounted just back of the work on the index head spindle (fig. 9-66). Disengage the index crank worm from the index head spindle so you can rotate simultaneously by hand the direct index plate, spindle, and work. An indexing pin, entering the index plate from the rear, locks the assembly and prevents unwanted rotation. You can produce any number of divisions, evenly divided into 24 (2, 3, 4, 6, 8, 12, 24), by this method. If you need to divide a piece of work into 6 equal parts, for instance, divide 6 into 24. The result, 4, is the number of holes to advance the index place for each cut.

In any indexing operation ALWAYS start counting from the hole adjacent to the crankpin. During heavy cutting operations, lock the spindle with the clamp screw to relieve strain on the index pin.

Plain indexing, using the universal index head, is governed by the number of times the index crank must be turned to cause the work to make one revolution. Index heads are available with ratios of 4:1, 5:1, and 40:1. The 40:1 index head is most common, so formulas based on this ratio are explained next. If you encounter an index head with a different ratio, just substitute that ratio for 40.



28.209X

Figure 9-66.—Direct index plate.

The number of turns of the index crank required to index a fractional part of a revolution is determined by dividing 40 by the number of divisions required. For example, if you are required to make 40 divisions on a piece of work, divide 40 by 40, indicating that one complete turn of the index crank is required for each division. If 10 divisions are required, divide 40 by 10; 4 complete turns of the index crank will be required for each division. The calculation for determining 800 divisions when an index plate with 20 holes is available, is as follows:

$$\frac{40}{800} = \frac{1}{20}$$

or 1 hole on the 20-hole circle

Suppose you need to make 9 divisions:

$$\frac{40}{9} = 4\frac{4}{9}$$

or 4 turns and 4 holes in a 9-hole circle

You will not be able to find a 9-hole circle, so you must multiply the numerator and denominator of the above fraction by the same factor to correspond with an available plate. If you have a plate with a 27-hole circle, your problem is solved since 9 divides into 27 three times, therefore:

$$\frac{40}{9} \text{ X } \frac{3}{3} = \frac{120}{27} = 4\frac{12}{27}$$

or 4 turns and 12 holes in a 27-hole plate

Occasionally, you may make a number of divisions that may lead to some complications, 52 for instance. It is doubtful that you will be able to find a plate with a 52-hole circle so you could reduce your fraction:

$$\frac{40}{52} = \frac{20}{26}$$

This will work if you have an available 26-hole circle. If not, you will need some further manipulation of the basic problem. Try dividing by a common factor:

$$\frac{40}{52} \div \frac{4}{4} = \frac{10}{13}$$

No 13-hole plate either? Then multiply the result by a common factor:

$$\frac{10}{13} \times \frac{3}{3} = \frac{30}{39}$$

You have a 39-hole plate so, as odd as it may seem, 30 holes in a 39-hole circle will produce 52 graduations.

When indexing is necessary, do not become discouraged by strange looking fractions. You can divide numerator and denominator by a number which divides evenly into both to find an appropriate index plate with a smaller number of holes, or you can multiply both by a common factor to correspond with an index plate with a larger number of holes.

To avoid the confusion of counting holes each time you index your work, be sure you set the sector arms (fig. 9-59) before starting. Advance the rear arm up to the index pin, then set the lead arm to span the correct number of holes. You can now lock the sector arms so they move together, but not independently. When you index your work and set the index pin next to the lead arm, simply slide the back arm up to the pin in preparation for your next indexing.

Angular indexing, although quite similar to plain indexing, is applied differently. Rather than dividing a workpiece into a number of evenly spaced sections, index your work to achieve a certain angular relationship between surfaces. Since the index head rotates at a 40:1 ratio, one turn of the index crank revolves the work 1/40 of 360°, or 9°. Therefore, 9° becomes the basis for computing required angles.

Suppose you need to produce several surfaces at an angle of 15° to each other. Simply divide the angle desired by 9:

$$\frac{15}{9} = 1\frac{6}{9}$$

You need to rotate the index crank one revolution and 6 holes in a 9-hole circle. You will not find a 9-hole circle, but an index plate with 54 holes is common. Therefore, multiply by a common factor to correspond with an available plate:

$$\frac{6}{9} \times \frac{6}{6} = \frac{36}{54}$$

One turn and 36 holes in a 54-hole circle will result in a 15° advance of the index head.

Now try this one: You need to produce some surfaces at 85° to each other, and you want to use a 27-hole circle:

$$\frac{85}{9} = 9\frac{4}{9} = 9\frac{12}{27}$$

or 9 turns and 12 holes in a 27-hole circle.

What will happen if a rotation of 25°10′ is called for? First of all, convert the 9° basic figure to minutes:

$$9 \times 60 = 540'$$

Then convert 25°10′ to minutes: 25 X 60 = 1500′ plus 10′ = 1510′. Now proceed as in previous examples:

$$\frac{1510}{540} = 2\frac{430}{540}$$

You may have already guessed that an index plate with 540 holes is going to be rather rare. How about reducing the fraction by a common factor?

$$\frac{430}{540} \div \frac{10}{10} = \frac{43}{54}$$

There it is. Two turns and 43 holes in a 54-hole circle.

MILLING MACHINE PRECAUTIONS

A milling machine operator's first consideration should be for safety, and you should attempt nothing that may endanger yourself or others. CARELESSNESS and IGNORANCE are the two great hazards to personal safety. Milling machines are not playthings and must be accorded the respect due any machine tool.

For everyone's safety, observe tne following precautions:

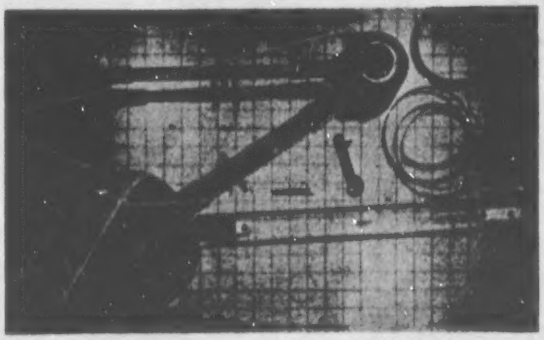
1. NEVER attempt to operate a machine unless you are sure you thoroughly understand it.
2. Do NOT throw an operating lever without knowing in advance the outcome. Before you attempt to operate any milling machine, study its controls thoroughly so that, if an emergency arises during operation, you can stop it immediately.
3. Do NOT play with control levers or idly turn the handles of a milling machine, even though it is not running.
4. Do NOT take a cut without being sure that the work is secure in the vise or fixture and that the holding member is rigidly fastened to the machine table.
5. NEVER lean against or rest your hands upon a moving table. If it is necessary to touch a moving part, be certain you know in advance the direction in which it is moving.
6. There is always danger to your eyes from flying chips. You MUST protect your eyes with goggles and keep them out of line of the cutting action.
7. ALWAYS remove chips with a brush or other suitable agent–NEVER with your fingers or hands.
8. Above all, KEEP CLEAR OF THE CUTTERS. Do NOT touch a cutter, even when it is stationary, unless there is a good reason for doing so. If you must touch it, be very careful.

CHAPTER 10

OPTICAL AND NAVIGATION EQUIPMENT

This chapter will cover most of the small instruments you will be required to work on as an Opticalman. We will explain the complete repair procedure for some of these instruments because there is no supporting technical manual. We will describe other instruments only briefly because technical manuals will be available to you at your duty station.

The instruments range from strictly mechanical navigation instruments to simple optical/mechanical devices through complicated precision optical instruments. Regardless of the simplicity or complication involved, you will have the opportunity to put to practical use all of the information contained in previous chapters of this book.



137.567

Figure 10-1.—Parallel motion protractor (bands removed).

PARALLEL MOTION PROTRACTOR

The parallel motion protractor (PMP) is a mechanical device used by the navigator to plot positions and courses (fig. 10-1). A transparent plastic scale is attached to a protractor head (360° graduations), which can be rotated a full 360° and locked in any position. Regardless of where you position the protractor head, the two arms, or the elbow joint, the scale will remain parallel to the original position as you move it over a chart. This parallel motion is obtained by single pulleys at the head and bracket and a double pulley at the elbow, fitted with steel bands (shown removed in figure 10-1).

The Mk 3 Mod 3 PMP (illustrated) is quite large. Each arm is approximately 18 inches long, and the protractor head is 7 inches in diameter. The fleet also uses smaller instruments which are similar. The repair procedures that follow will generally apply to most types of PMP's.

DISASSEMBLY

Prior to disassembling a PMP, or any other instrument, thoroughly inspect the mechanical operation, function, and appearance, and note defects on an inspection sheet. Although we will cover complete overhaul in this manual, it is not practical to disassemble an instrument further than necessary to make repairs and adjustments to restore the device to normal operating condition. Refer frequently to the numbered items in figure 10-2 (see foldout at end of chapter) as we explain the disassembly procedure.

1. Remove three screws (59) from the handle (38) and lift off the handle. Now unscrew the scale lock "L" nut (6) and remove the spring (8). While holding the base plate (3), remove nut (63) with a socket wrench; then lift

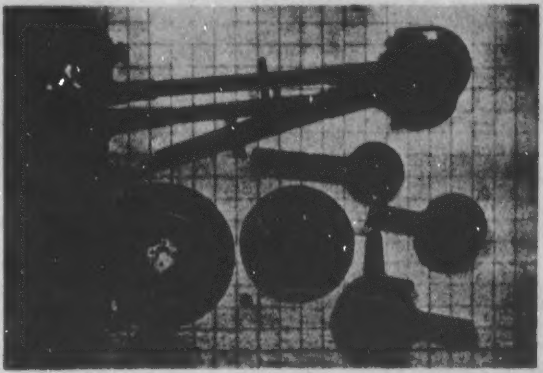
the head off the bench and tap the end of the spindle unit (4) with a fiber mallet to drive it out of the head. Notice that a pin through the spindle engages a slot in the witness plate (31) so when the scale is unlocked, the base plate (3) turns the witness plate. Remove the protractor lock (1) and "L" nut shim (40). Now you can remove the brake screw (46) from the protractor lock plate (2) and separate the protractor (32) and the witness plate (31). Slip the scale lock screw (7) away from the friction plate riveted to the protractor. NOTE: Do not mix up the component parts of the scale lock and protractor lock.

2. Remove the four band covers (45) (if so equipped). These covers are made from thin formed steel and are friction fitted between the upper and lower elbow brackets (9) and the fork bracket (28) and head bracket (37). The covers are U-shaped (open on the bottom). Grasp the cover several inches from the elbow bracket, squeeze slightly, and slide the cover into the elbow bracket until the other end clears the head or fork bracket. Then lift the cover free and slide it out of the elbow bracket. NOTE: Do not crimp or bend the covers.

3. Remove tension on the bands by turning the upper (47) and lower (50) tubes clockwise. The pins (49) provide a finger hold. Thrust screws (57) in the tubes are slotted, so you can insert a pin punch or small screw driver in holes in the upper and lower elbow brackets (9) to hold the screws while rotating the tubes.

4. Remove the head pulley band. If the band is not loose enough to slip over the pulley (33), repeat step 3. Once the band is removed, pull the head bracket (37) away from the lower tube (50) and remove the tube. Do not lose the two thrust plugs (56). Use a socket to remove nut (39) from the spindle bushing (34) and tap out the spindle bushing from the bottom with a fiber mallet. (This will separate the head into the major components shown in figure 10-3).

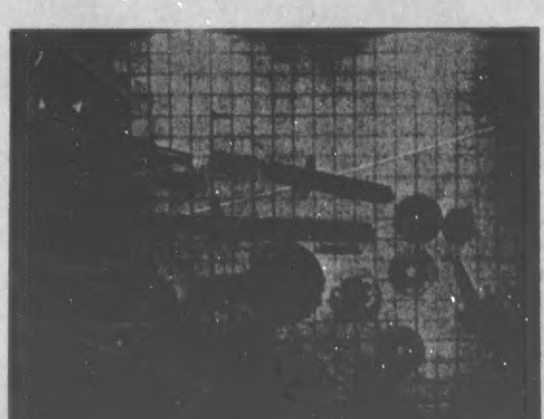
5. Remove the band from the mass pulley (27). See step 3 if the band is too tight to slip off. Pull the elbow bracket (9) away from the upper tube (47) and remove the tube and thrust plug (56). Notice that the upper and lower tubes are not interchangeable.



137.569

Figure 10-3.—Parallel motion protractor head components.

6. To disassemble the elbow bracket, remove the brake knob (11). This will free the lower brake shaft (13) and plate (14) and the upper brake (16). With two socket wrenches, unscrew the elbow nut (19) from the elbow spindle (17). This will free the upper and lower elbow brackets (9), the upper and lower brake linings (15) and disc (18), and the elbow pulley (10). (See figure 10-4.) NOTE: Protect all components from possible damage from nicks or bending.



137.570

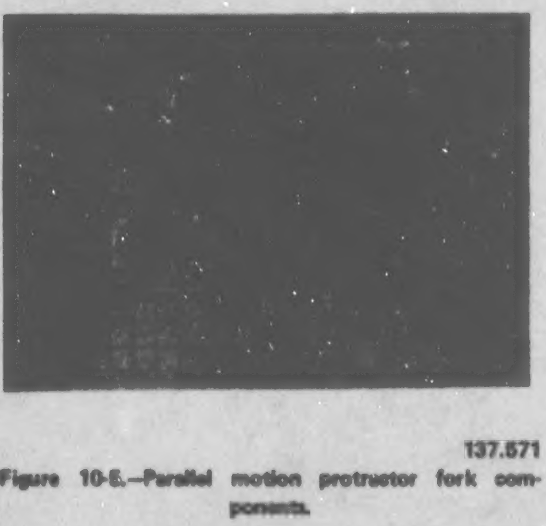
Figure 10-4.—Parallel motion protractor elbow components.

7. Remove the brake knob (11) and brake (16) from the fork bracket (28). Unscrew the elbow nut (19) with a socket, freeing the brake disc (18) and lining (15). Now remove screws (68), (71) and (74) to remove the tube support (58) and fork bracket (28). Remove the hinge mounting mast screw (42) from the hinge mounting (21), and pull out the mast (44). The disassembled components are shown in figure 10-5.

8. It is usually unnecessary to disassemble the PMP any further unless it is to be stripped and painted or unless damaged bearings are to be replaced. Check bearings by rotating them with your fingers. They should roll smoothly without catching, jumping, or binding. If you note any defects, the bearings must be replaced. You can carefully press out and replace bearings either by using a bench vise and two sockets, as shown in figure 10-6, or by using an arbor press.

INSPECTION, CLEANING, REPAIR, REASSEMBLY

Most defects in the PMP can be detected during the pre-disassembly inspection and verified upon disassembly. Perhaps the most serious casualty is a damaged pulley. There can be no nicks, burrs, or eccentricity, and all pulleys must be exactly the same diameter to provide parallel motion of the scale attached to the base plate.



137.571

Figure 10-5.–Parallel motion protractor fork components.

137.572

Figure 10-6.–Parallel motion protractor bearing removal.

Carefully mask parts that require repainting or touch up so that no paint touches bearing surfaces, brake components, threads, or spindles. Black wrinkle finish is preferred, and most durable, for all parts except those which are engraved. Semigloss enamel is used on these components, followed with a Monofil application on markings.

Clean PMP parts with paint thinner or a similar solvent to remove oil and dirt. Blow dry the cleaned parts and wipe them with a clean, lint-free cloth. The pulleys, bands, and brakes must remain absolutely free of oil or grease.

Occasionally, a PMP will be sent to the shop with a broken or kinked band. Kinks are not easy to remove, but you can work them out on a surface plate or other smooth surface with a fiber mallet. If the kink is severe, cut out the damaged portion and grind the ends square. (The same procedure is used for a broken band.) Once the ends are squared, weld the band together, using the welding attachment on a bandsaw. After welding, dress the seam down with a fine sharpening stone. The bands used on a PMP do not need to be the same length to function properly. They do have to be long enough to allow installation, removal, and tension adjustment.

Prior to assembly, check all threads for damage. Restore damaged areas or, if necessary, replace the parts. Also check brake components for damage and replace unsuitable parts.

Reassembly of the PMP is done in the reverse order of disassembly. Bearings, spindles, and threads should be lightly lubricated.

NOTE: Do not allow any grease on brakes, bands, or pulleys.

When you adjust the PMP bands, they should be tight enough to "ping" when plucked. They must be tight enough to prevent slipping on the pulleys but not so tight as to be strained. After the bands have the proper tension, turn the tube tightening pins (49) so they are parallel with the work bench.

After the PMP is assembled, the scale lock and protractor lock should be in the position shown in figure 10-2 when they are locked. If this condition is not met, remove the "L" nuts (6) and turn a 10-32 screw into the "L" nut to remove the threaded bushing. Turn the bushings snugly back on the brake screw (46) and/or scale lock screw (7), then tap the "L" nuts on to the bushings, in the proper position, with a fiber mallet.

NOTE: Support the protractor directly under the "L" nut with a block of wood while reseating the "L" nuts.

The brakes on the elbow bracket and fork bracket are merely friction brakes to prevent unwanted movement while the PMP is in use--they do not lock these brackets.

For final adjustment of the PMP, mount the hinge mounting (21) on the anchor plate (25), and tighten and lock the anchor screw (26). Mount any convenient scale on the base plate (3) and swing the scale to see if it passes freely under the elbow bracket. To make this adjustment, turn set screw (23) and lock the adjustment with jam nut (24). If the top of the elbow pulley (10) is not aligned with the mast pulley (27), alternately loosen and tighten screws (71) and (74) to raise or lower the tube support (58). Then recheck scale clearance under the elbow bracket.

Place a large sheet of clean paper on your workbench under the PMP scale. With the PMP in the position shown in figure 10-1, draw a line on the paper along the scale. Manipulate the PMP so the elbow bracket is on the left side and the scale is in the approximate original position. Using the rule, now draw another line parallel to the first line. If the two lines are parallel, your repair and adjustment have been accomplished correctly. If the lines are not parallel, the scale lock could have been loose, the bands may not be tight enough, they may be dirty, or there may be some misalignment or looseness in the PMP. Another common cause of nonparallelism is that the bands may not be seated in the pulley grooves. Recheck all phases of assembly and adjustment until parallel lines are produced.

MAGNETIC COMPASS

The Navy has equipped all its ships with GYROCOMPASSES, but the large ships also have MAGNETIC COMPASSES similar to that shown in figure 10-7. Ships' boats depend

45.595(69)

Figure 10-7.—U. S. Navy 7 1/2-inch magnetic compass.

45.23

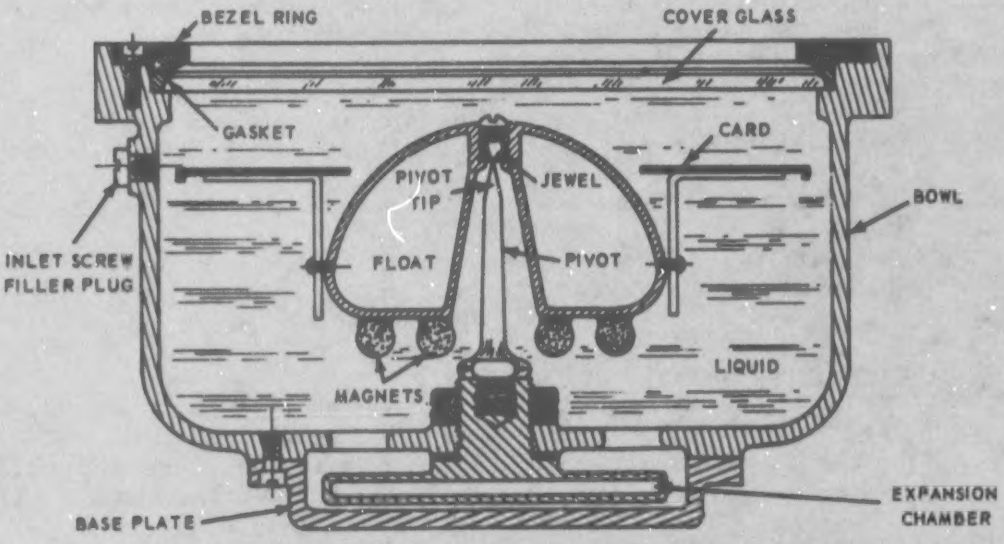
Figure 10-8.–Standard 4-inch boat compass.

entirely on the magnetic compass shown in figure 10-8.

The size of a compass is designated by the diameter of the compass card. The large 7 1/2-inch compass shown in figure 10-7 is complete with gimbal ring, and the 4-inch boat compass in figure 10-8 has the gimbal ring removed. When a magnetic compass is mounted in a ship or boat, the gimbal ring arrangement keeps the compass level regardless of the motion of the vessel.

For a complete examination of compass nomenclature, refer to figure 10-9. The compass bowl is completely filled with varsol (mineral spirits) or a mixture of 45% alcohol (190 proof) and 55% distilled water. For obvious reasons, the compass fluid must not freeze. By using a fluid filled compass, the float assembly (float, compass card, and magnets) is stabilized against vibration, pitching, and rolling. Also since the float assembly is lighter when submerged, it is more sensitive to magnetic attraction of the Earth's poles. (The float assembly of a 7 1/2-inch compass weighs 3,060 grains in air and 90 grains submerged.)

The compass bowl is made of cast brass or bronze (nonmagnetic). The top is machined to accept a thick cover glass, a gasket recess, and a bezel ring to hold the glass and compress the gasket. The bezel ring is secured with 8 to 12 screws, depending on the size of the compass. NOTE: Except for the magnets, a compass must be constructed of nonmagnetic materials.



137.288

Figure 10-9.–Nomenclature of a magnetic compass.

The float is a hollow, sealed chamber with magnets soldered to the bottom, a synthetic sapphire pivot jewel held in the center, and a compass card riveted to the outside. The compass card is very thin and fragile. Markings on the compass card (fig. 10-8) are stamped out of the card.

Rather than having four bar magnets, the compass has magnets that are actually bundles of small magnetic wires. This arrangement provides more magnetic attraction than solid bars.

A tough metal pivot is attached to the expansion chamber to support the float assembly and to hold it in the center of the compass bowl. The pivot tip is formed with a very small radius to reduce friction against the pivot jewel. You may suspect by now that the float assembly must be balanced in order to function properly. Balancing is accomplished by adding or removing solder on the bottom of the float.

An expansion chamber is secured to the bottom of the compass bowl and protected by a base plate. The expansion chamber is a thin metal bellows which compensates for expansion and contraction of the compass liquid caused by temperature changes. The compass in figure 10-9 uses a sealed hollow chamber which is surrounded by liquid. You will run across compasses that have the expansion chamber surrounded by air but are open to the compass bowl liquid.

INSPECTION AND DISASSEMBLY

When a compass is sent to the optical shop for repair, a careful inspection will usually indicate probable defects prior to disassembly. The following list of defects/causes should be beneficial.

- If the compass card is level and there is a large bubble under the glass cover, liquid is leaking around the cover glass or filler plug, or there is a leak in or around the expansion chamber.

- If the compass card is tilted and a large bubble is under the glass cover, there is probably a leak in the float.

- If there is no bubble under the cover glass but the card is tilted, the magnets have shifted, or the balancing solder has fallen off the float, or the float has jumped off its pivot.

- Put the compass on a level workbench and turn it until the north point on the card is at the lubber's line (vertical line in the bowl). With a magnet, deflect the compass card exactly 11° and then quickly remove the magnet. The card will then swing back; as the zero mark crosses the lubber's line, start a stopwatch. The zero mark will reach the end of its swing and start back; as it crosses the lubber's line the second time, stop your stopwatch and read it. The time you read is THE PERIOD OF THE COMPASS, and it should be 10 seconds or less. If it is longer than 10 seconds, the magnets are weak, or the pivot point is in poor condition.

- If the float does not swing freely under the influence of a magnet, the pivot point or the jewel is broken.

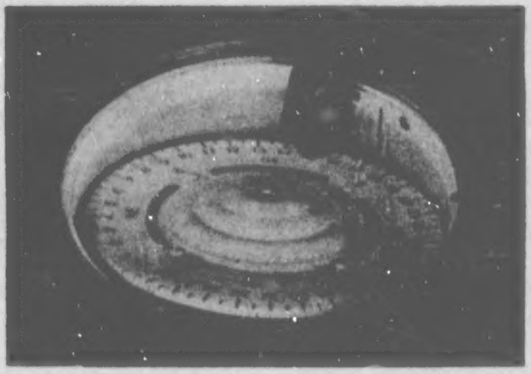
The recommended procedure for disassembling a magnetic compass is as follows:

1. Remove the filler plug and drain out a small quantity of the liquid to prevent spillage when trying to handle a full compass bowl. Then replace the filler plug. Save the liquid you drew out.
2. Mark the lip of the bowl and the edge of the bezel ring, because you must put the bezel ring back in the same position it occupied before removal.
3. Remove screws from the bezel ring.

CAUTION: Loosen each screw a little at a time, in rotation or opposite each other, to prevent tilting of the bezel ring and possible breakage of the glass.

4. Lift off the bezel ring and then remove and discard the rubber gasket.
5. With a suction gripper (fig. 10-10), lift the glass. CAUTION: The glass is beveled to a thin edge and chips easily.
6. Test the float for leaks. Push down on one side of the float, as shown in figure 10-11, hold it down for several seconds, and then

137.288
Figure 10-10.—Removing the cover glass.



137.289
Figure 10-11.—Testing the float for leaks.

release it. Repeat this test at three different points around the card. If the float stays down at each of the three positions, it contains liquid. If the float stays down at only one position, the problem is caused by loss of balance.

7. With a piece of wire bent to form two hooks (fig. 10-12), lift the float out.

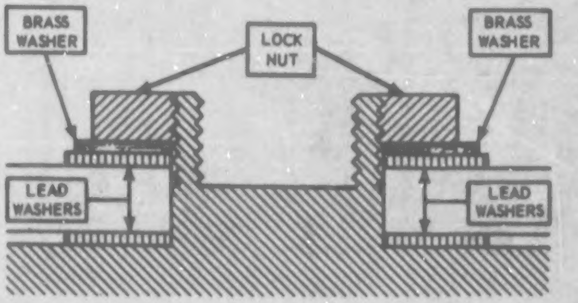
8. Pour the remainder of the liquid from the bowl, and filter it through filter paper or absorbent cotton into a clean bottle for future use.

9. To remove the pivot, fit a socket wrench over its hexagonal base and turn counterclockwise. CAUTION: Be sure the center hole of the wrench is deep enough to provide clearance for the pivot point.

137.290
Figure 10-12.—Removing the float assembly.

10. Turn the bowl over and, with a punch, make light register marks on the bowl and the base plate to guide you in reassembling the base plate in its original position. Remove the screws from the base plate and lift it off.

11. Figure 10-13 shows a typical method of securing the expansion chamber to the compass bowl. Beneath the lock nut is a brass friction washer, and under this washer is a lead washer. Between the chamber and the bottom of the bowl is another lead washer. When these washers are put under pressure, they seal the opening in the bottom of the bowl. Turn the bowl over and



137.292
Figure 10-13.—Expansion chamber secured to bottom of compass bowl.

remove the expansion chamber lock nut with a socket wrench. CAUTION: Do not set the compass down on the expansion chamber.

12. Remove the expansion chamber from the bowl and inspect it for leaks or other damage.

REPAIR AND ASSEMBLY

Inspection of parts, repair, and reassembly of a magnetic compass are discussed together step by step, as follows:

1. If the expansion chamber is in good condition, reassemble it. CAUTION: Do NOT forget the lead washer between the expansion chamber and the bottom of the bowl. If this washer is not in perfect condition, replace it.

2. Replace the second lead washer, inside the bowl, and replace the brass friction washer. If necessary, use a new washer. Start the hexagonal lock nut by hand and tighten it with a socket wrench. NOTE: Use enough tension to seal the lead washers.

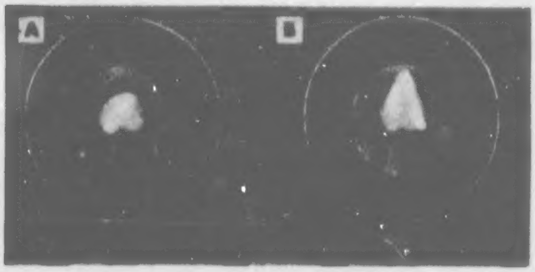
3. Put the base plate back into position; then replace the base plate screws and tighten them. CAUTION: Be sure to line up the marks you made during disassembly; otherwise, the compass will be out of balance.

4. With a magnifying glass, inspect the pivot point for wear. Study figure 10-14. The magnified pivot in part A is badly worn and rounded. The pivot in part B is properly shaped. NOTE: A badly worn pivot point makes a compass sluggish.

5. If the pivot point is worn, put it in a lathe and reshape it with a fine carborundum stone (fig. 10-15). Then polish it with a hard Arkansas oilstone and inspect again for correct shape. The tip of the pivot should have a radius of .005 inch.

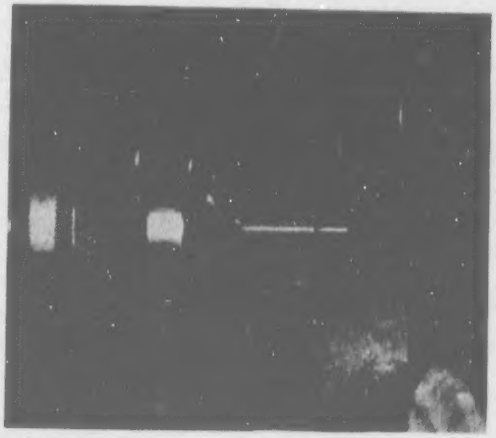
6. Remove the screw from the top of the float and use a piece of pegwood with a rounded end to push the jewel and its spacer out of the float. Study figure 10-16. CAUTION: Be extremely careful at all times when handling the float to avoid damage to the compass card. Hone a steel needle to a sharp point on an oilstone and rest it on your fingernail (fig. 10-17). If it slides under its own weight, it is NOT sharp enough; if it catches on your thumbnail, it has correct sharpness. Now slide the needle under its own weight over the whole bearing surface of the jewel, as shown in figure 10-18. If the surface of the jewel has a crack or a pit, it will snag the fine point of the needle. NOTE: If the jewel is defective, replace it.

7. Test the float for leaks by submerging it in warm water (120°F). The heat will expand the air inside the float; if there are leaks in the float, air will bubble out through them. Use a pencil to mark the position of leaks.



137.293

Figure 10-14.—Pivot points.



137.294

Figure 10-15.—Shaping a worn pivot point.

137.295
Figure 10-16.–Removing the jewel from the float.

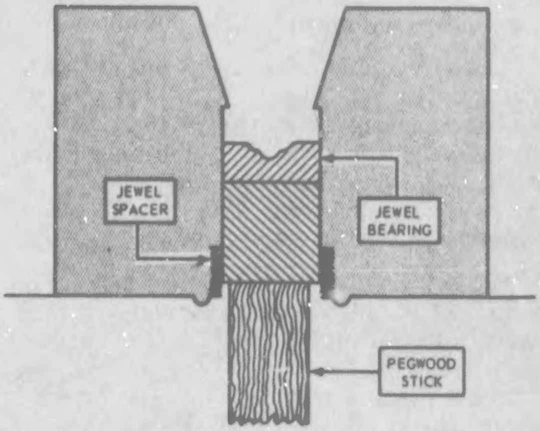
137.296
Figure 10-17.–Testing a needle for sharpness.

If the float has a leak, drill a small vent hole in it, drain out the liquid, and dry the float in an oven at 150°F. Then scrape the float down to base metal at each leak, clean the metal, and solder all leaks. Scrape the area around the vent hole and close the hole with solder.

137.297
Figure 10-18.–Testing a pivot jewel with a needle.

Put the float back into warm water and recheck for leaks. NOTE: Leaks in the cone section of the float are difficult to close; if you cannot seal them, replace the float.

8. Use a pegwood stick with a flat end to press the jewel and its spacer back into the float, as shown in figure 10-19. Then replace the retaining screw and tighten it. CAUTION: Do NOT use force; too much pressure will crack the jewel.



137.298
Figure 10-19.–Replacing pivot jewel and spacer.

137.299

Figure 10-20.—Equipment for testing float balance.

9. When you repair a float or replace a jewel, you generally destroy the balance of the float and must rebalance it. Materials required for making a float balance test are shown in figure 10-20.

10. To remove bubbles from under the compass card and the cone section of the float, immerse the float edgewise in the compass liquid in the jar, as illustrated in figure 10-21. Then ease the float onto the pivot.

11. Set the point of your sighting rod at the same height as the compass card and spin the float with a magnet. See figure 10-22. As the card spins, compare its level with the sighting rod. If the float is balanced, the card will stay level while it is spinning. If the float is out of balance, it will wobble as it turns.

Remove the float and scrape a clean spot on its edge at the high point. Then apply a small amount of solder at this spot. Put the float back on the pivot and retest for balance, and keep adding solder and retesting until you have the float in perfect balance. NOTE: If you apply too much solder, scrape some of it off with a knife.

12. Inspect the seats for the cover glass and the rubber gasket. If they are corroded, scrape

137.300

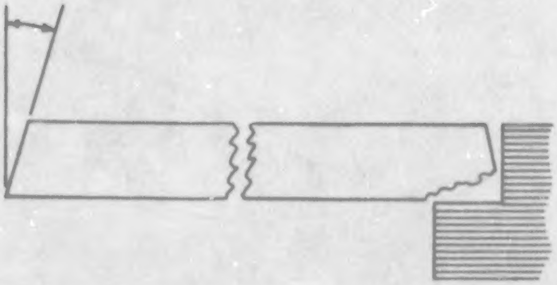
Figure 10-21.—Mounting the float for a balance test.

137.301

Figure 10-22.–Making the balance test.

them by hand or remove the corrosion on a lathe. Then clean the surfaces thoroughly with an approved cleaner. NOTE: These surfaces must be perfectly flat and smooth.

13. Inspect the beveled edge of the glass cover. NOTE: The side which seats against the bowl has the larger diameter. If there are any chips on this edge, as shown in figure 10-23, replace the cover glass.



137.305

Figure 10-23.–Inspection of a cover glass.

14. Clean the compass bowl with a soft brush to remove lint or other foreign particles, then blow out with low-pressure air.

15. Fill the expansion chamber with compass liquid, using a rubber syringe. When the chamber is filled in this manner, trapped air will be forced out.

16. Replace the pivot and tighten it with a socket wrench.

17. At several points, measure the distance from the rim of the bowl to the tip of the pivot. NOTE: The pivot point should be exactly centered in the bowl. If necessary, bend the pivot with a pair of pliers. Be careful to avoid damaging the pivot point.

18. With wire hooks, lower the float onto the pivot. Check the distance between the edge of the card and the inner rim of the bowl. If it is not the same all the way around, remove the float and readjust the pivot.

19. Remove the float and fill the bowl with compass liquid to a level one-half inch below the cover glass seat.

20. Replace the float and, with a pegwood stick sharpened to a chisel point, carefully place the glass in position. Be sure the inside of the glass is clean.

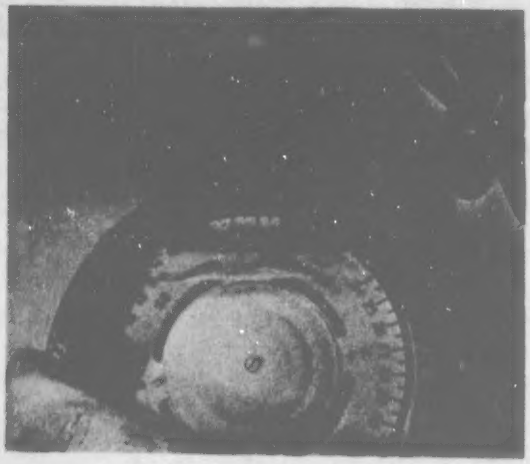
21. Fit a new rubber gasket around the edge of the cover glass. The gasket material comes in a roll, and it must be cut to size for each compass. Cut the ends square with a razor blade so the ends butt perfectly together when properly installed.

22. Replace the bezel ring, insert the screws, and turn them tight with your fingers. Then use a screwdriver to tighten all screws, one-half turn at a time in rotation, until the ring is secure.

TESTING AND ADJUSTING

The procedure for testing and adjusting your reassembled compass is as follows:

1. To test for leaks around the bezel ring, or expansion chamber, make a screw to fit the filler hole and drill a small hole through the center of the screw. Insert the screw in the filler hole and fit a piece of rubber tubing over the screw. Suck on the tube to pull a slight vacuum



137.309

Figure 10-24.—Testing for leaks around the bezel ring.

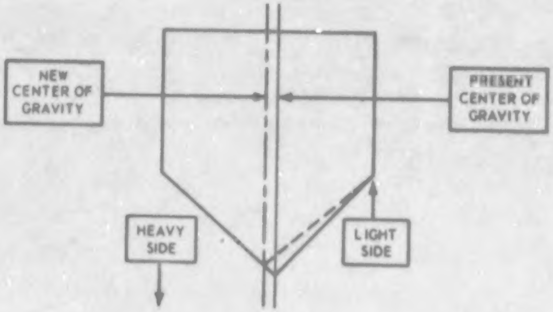
and then pinch it off (fig. 10-24). Roll the compass slowly from side to side to see if any bubbles appear around the bezel ring. Set the compass on its base and see if any bubbles rise from the bottom. All such leaks must be stopped before you fill the compass.

2. With a rubber bulb syringe, finish filling the bowl with liquid; then replace the filler plug and secure it.

3. Put the compass in a warm place and let it stand for 24 hours with the filler hole up. This amount of time allows trapped bubbles to rise and dissolved air to come out of the compass liquid. NOTE: Less time is satisfactory if the air is fairly warm. Remove bubbles by adding more liquid and then replace the plug.

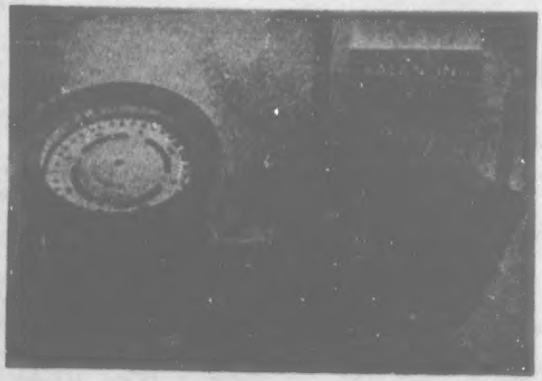
4. Retest the period of the compass as explained at the beginning of the inspection and disassembly section.

5. Balance the compass using the equipment shown in figure 10-25. The compass must balance on its lugs, and the compass and gimbal ring must balance as a unit. When you place the spirit level on the compass cover glass, be sure it is centered so you do not get a false balance.



137.312

Figure 10-26.—Restoring compass balance.



137.310

Figure 10-25.—Equipment for testing compass balance.

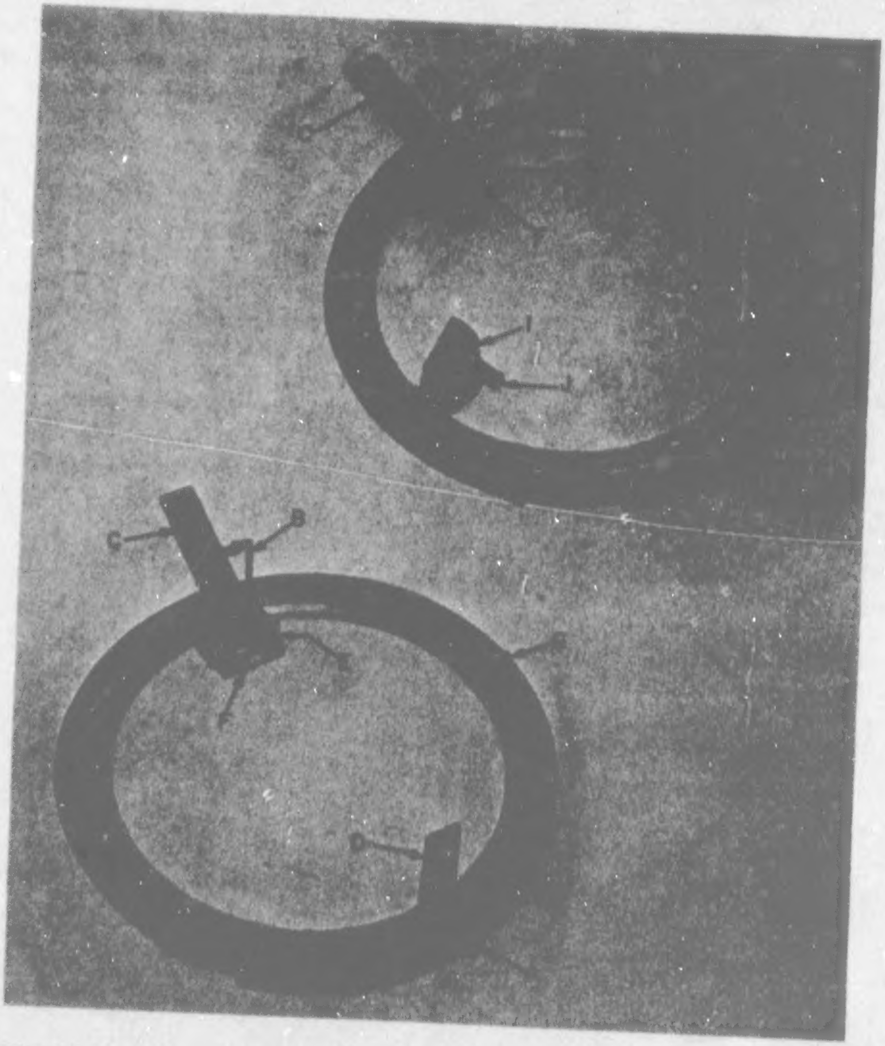
45.23

Figure 10-27.—Final balance test.

If your compass does not balance, file the lugs to move the bearing edge over toward the heavy side (fig. 10-26). Make a light cut with your file and test the balance. Repeat this process until the balance is perfect on the compass and the compass and gimbal ring. See figure 10-27.

AZIMUTH AND BEARING CIRCLES

The azimuth and bearing circles, shown in figure 10-28, are used on the bridge of ships to aid in navigation. These instruments are



A. Counterweight
B. Front sight
C. Black mirror
D. Rear sight
E. Penta prism
F. Penta spirit level
G. Hand knob
H. Curved mirror
I. Right-angled prism assembly
J. Right-angled spirit level

Figure 10-28.—Mark 3 Mod 2 Azimuth circle and Mark 1 Mod 2 bearing circle.

65.122

constructed entirely of nonmagnetic materials since they are used on gyrocompass repeaters or 7 1/2-inch magnetic compasses.

True and relative bearings of terrestrial objects and the azimuth of celestial objects can be measured with the sights mounted at 0° and 180° on both instruments. The movable mirror and right angle prism assembly on the azimuth circle (90°-270°) are used to measure the azimuth of the sun.

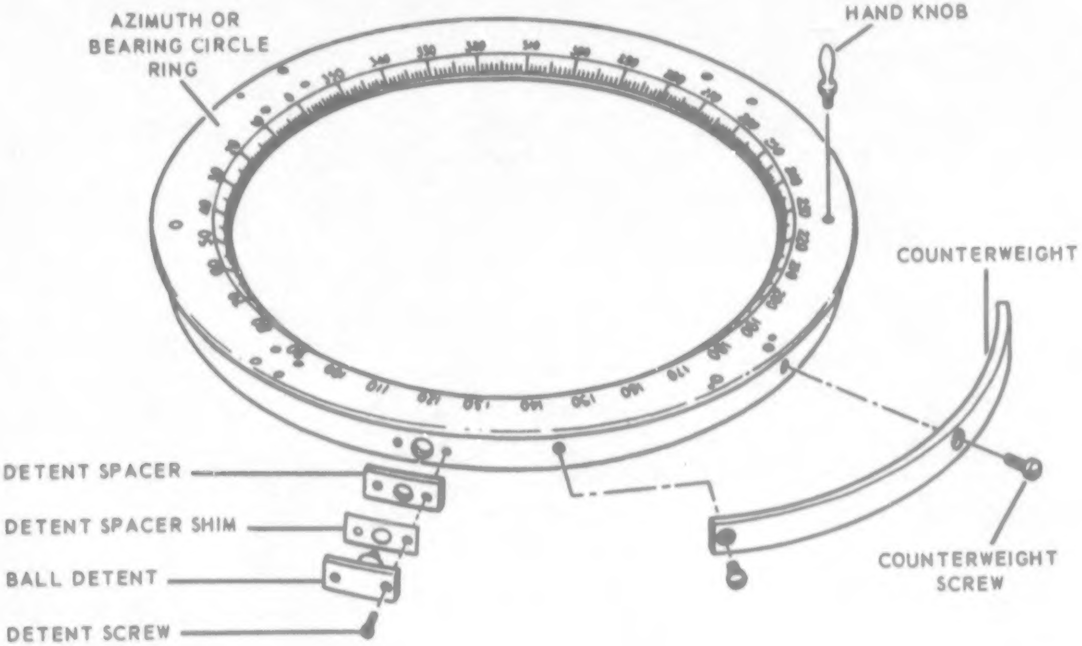
The graduations on the bearing ring of both instruments run counterclockwise. To measure a relative bearing when the sights are aligned with an object, merely read the bearing aligned with a lubber's line engraved on top of the compass or repeater. If the true bearing is needed, read it directly from the compass card.

Notice the spirit levels on the 0°-180° and 90°-270° sights. If the instruments are not level when a sighting is made, the azimuth or bearing reading will be inaccurate. Likewise, since these instruments are basically a small mechanical sighting device, you must adjust them perfectly during overhaul to obtain accurate readings.

CONSTRUCTION FEATURES

The azimuth or bearing circle ring (fig. 10-29) is common to both instruments. The only difference is the additional set of sights (90°-270°) on the azimuth circle. The ring must be perfectly flat and concentric, otherwise accurate readings would be impossible. Three spring detents (120° apart) hold the ring firmly on a compass or repeater.

The rear sight assembly, shown in figure 10-28, consists of a bracket held to the bearing ring with screws aligned with dowel pins. The vertically slotted sight leaf pivots on a friction pin through the sight and bracket.



137.573

Figure 10-29.—Azimuth or bearing circle ring.

The complete front sight assembly (fig. 10-30) consists of various subassemblies. Due to the nature of the construction of this assembly, numerous adjustments can be made to align components during collimation. The front sight wire is made from .011-inch brass. If loose, it can be tightened; when kinked or broken, it must be replaced. The pins that the front sight and black mirror pivot on should be tight enough to hold these elements in any position, but still allow them to be moved. During collimation, you must adjust the black mirror, front sight, bottom sight wire, and spirit level to align perfectly with a plane passing through the 0°-180° graduations and perpendicular to the collimator stand.

An exploded view of the right angle prism assembly is shown in figure 10-31. Alignment adjustments are provided on the spirit level assembly, prism bracket, and slotted bottom cover. This assembly, located on the azimuth circle ring at 90°, is used in conjunction with the curved mirror (fig. 10-32) mounted at 270° on the azimuth circle ring. When properly adjusted,

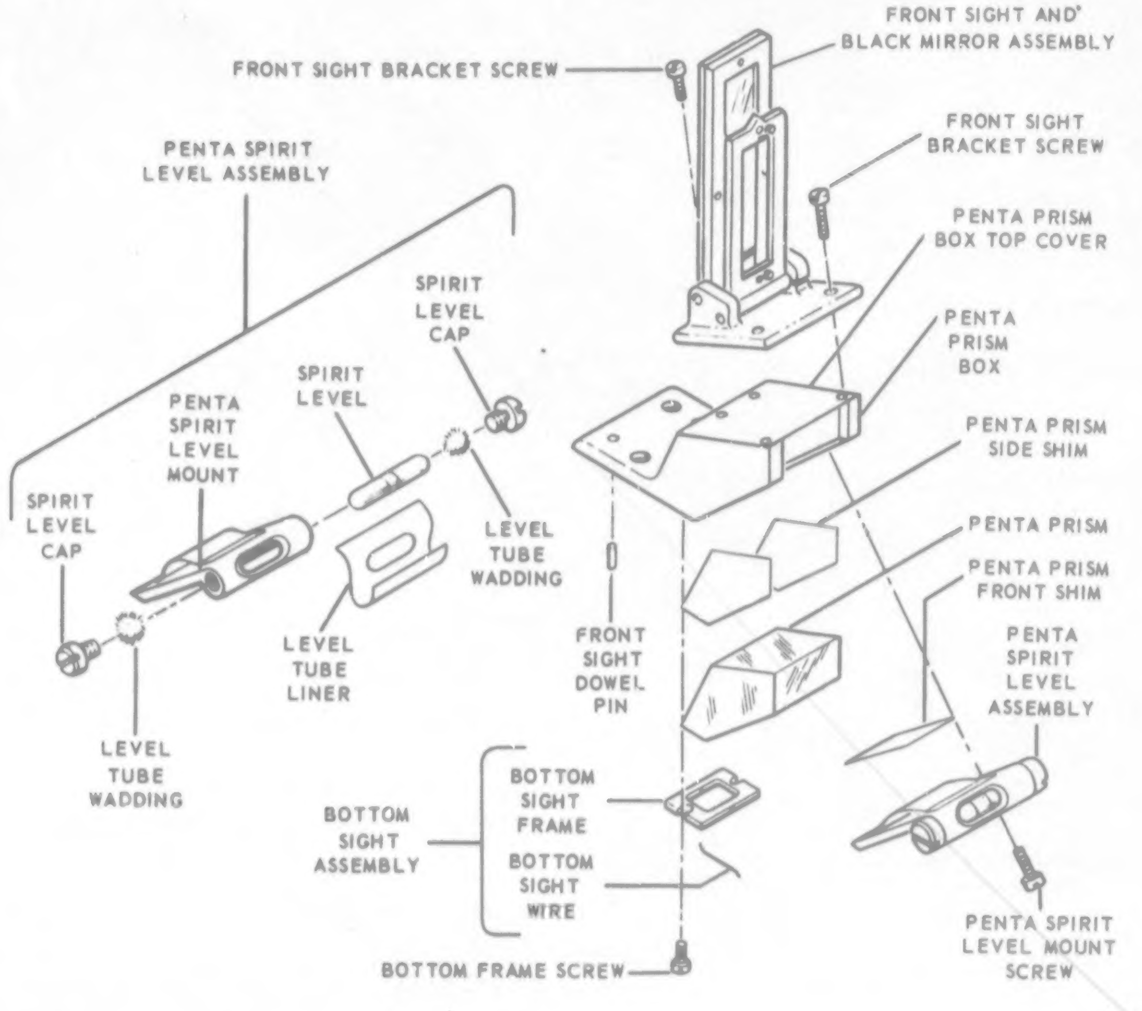


Figure 10-30.–Front sight assembly.

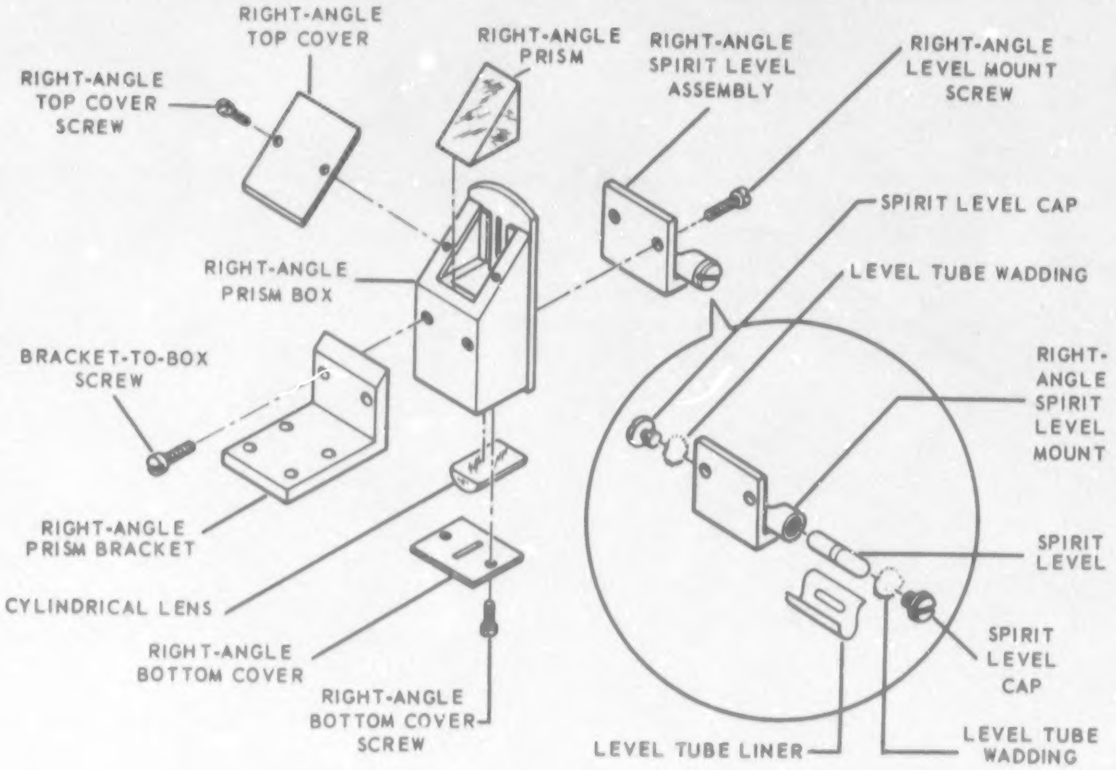
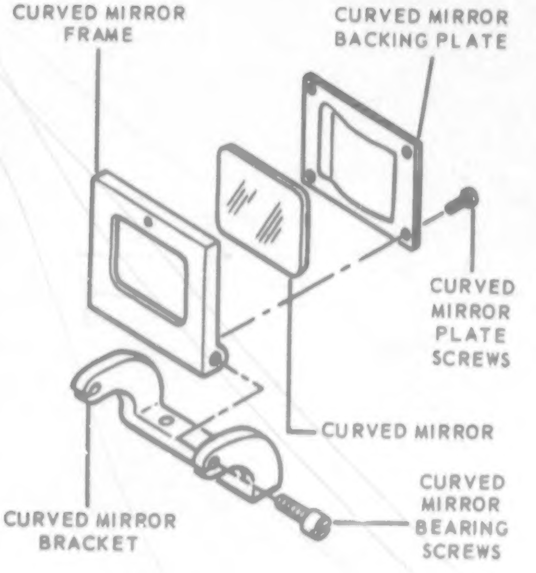


Figure 10-31.—Right angle prism housing assembly. 137.575


CURVED MIRROR FRAME
CURVED MIRROR BACKING PLATE
CURVED MIRROR PLATE SCREWS
CURVED MIRROR
CURVED MIRROR BEARING SCREWS
CURVED MIRROR BRACKET

137.576

Figure 10-32.—Curved mirror assembly.

the reflection of the sun is directed toward the slot in the front of the right angle prism box. The prism reflects this wide band of light to the cylindrical lens which focuses a narrow band of light onto the compass card. The spirit level must indicate a true level, and all reflection and refraction must take place in a plane passing through the 90°-270° graduations and perpendicular to the collimator stand.

REPAIR AND ADJUSTMENT

A thorough predisassembly inspection will usually pinpoint areas where work is needed. Check all optics for chips, scratches, and where appropriate, deteriorated silvering. Look for missing paint and corrosion on metal surfaces, and be sure the graduation marks are readable. Check the action of movable components to detect binding or looseness.

Obvious damage to sights caused by carelessness or accidental dropping is easy to detect, but a warped bearing ring can only be checked and straightened on a special circle repair ring (which you can manufacture if necessary).

A typical collimation setup is shown in figure 10-33. First, level the collimator stand, then place a machinist's square on the stand with its vertical edge touching one of the dumb lines engraved on the stand. Turn on the artificial sun and rotate the stand until the

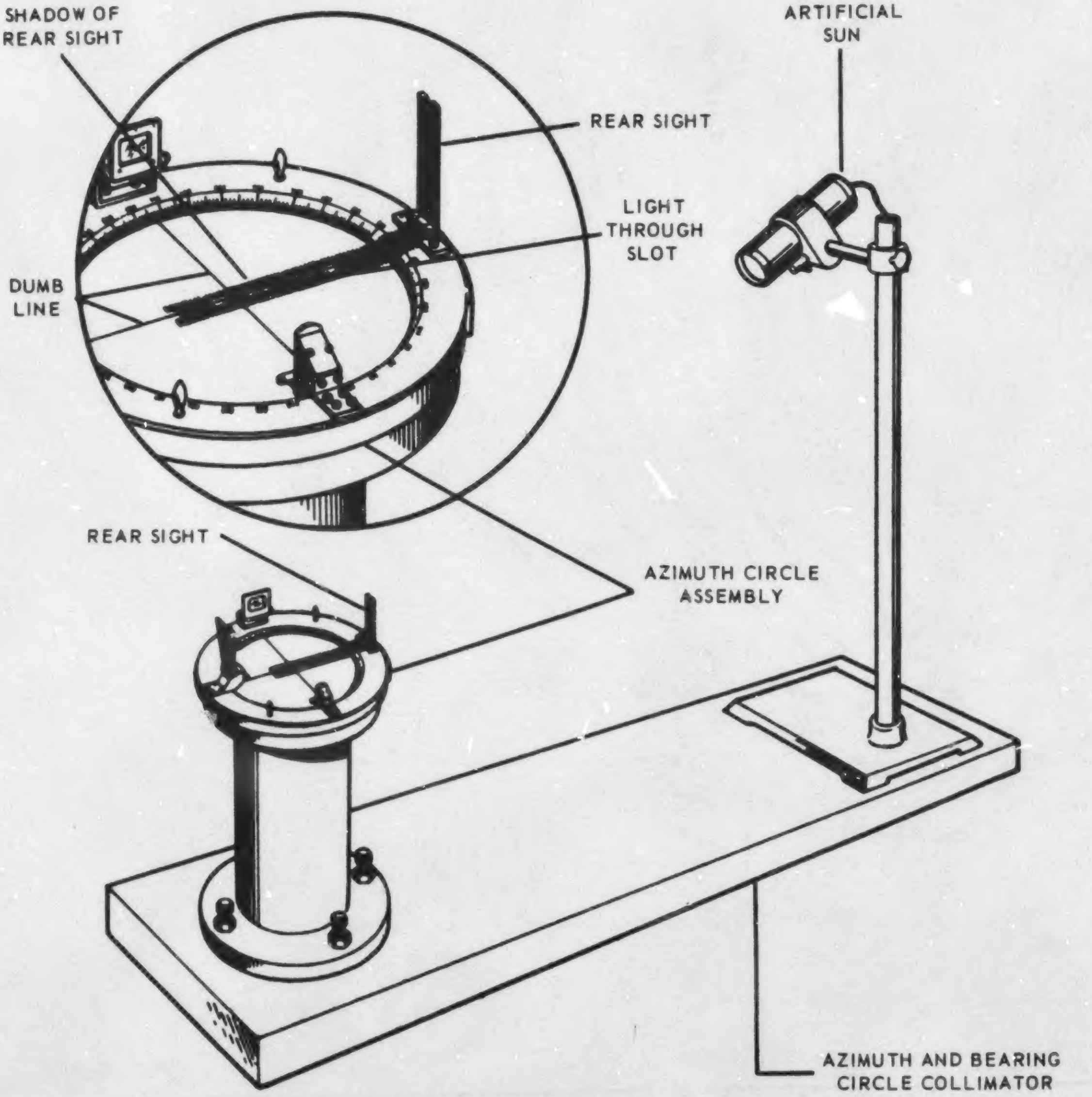
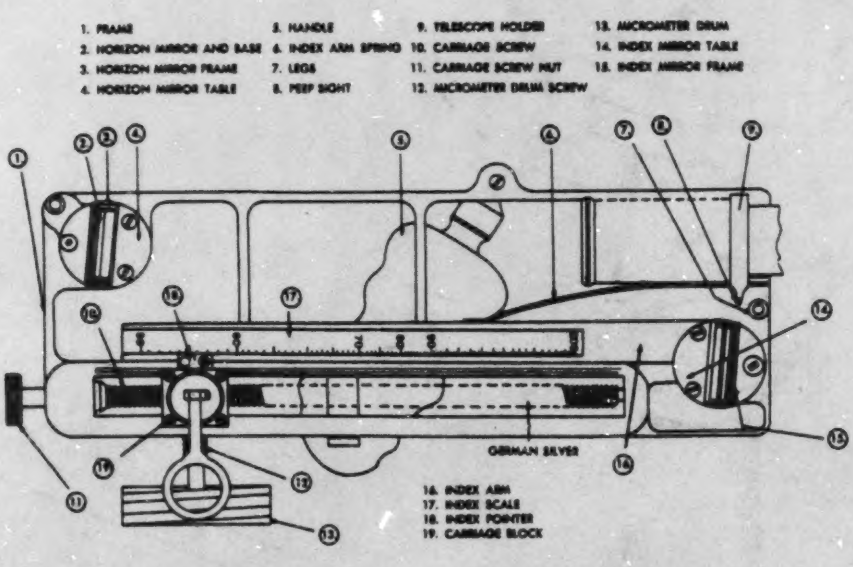


Figure 10-33.–Azimuth and bearing circle collimator.

58.78.2

Figure 10-34.—The Fisk stadimeter.



137.364

Figure 10-35.—Construction of a Fisk stadimeter.

shadow cast by the machinist's square falls on the dumb line. Then lock the stand in position.

When collimating the azimuth or bearing circle, check all adjustments by observing the light or shadow cast on the collimator stand by the artificial sun. NAVSHIPS 250-624-7 contains complete overhaul information for the azimuth and bearing circle.

STADIMETER

The stadimeter is a small, hand held navigation instrument shown in figures 10-34 and 10-35. It is used to measure range between ships or to prominent landmarks (from 200 to 10,000 yd) when the height of the object is known (between 50 and 200 ft). When properly adjusted and carefully used, the distance to objects up to 2,000 yards can be measured with an accuracy of ±2%. Beyond 2,000 yards, accuracy rapidly decreases.

CONSTRUCTION

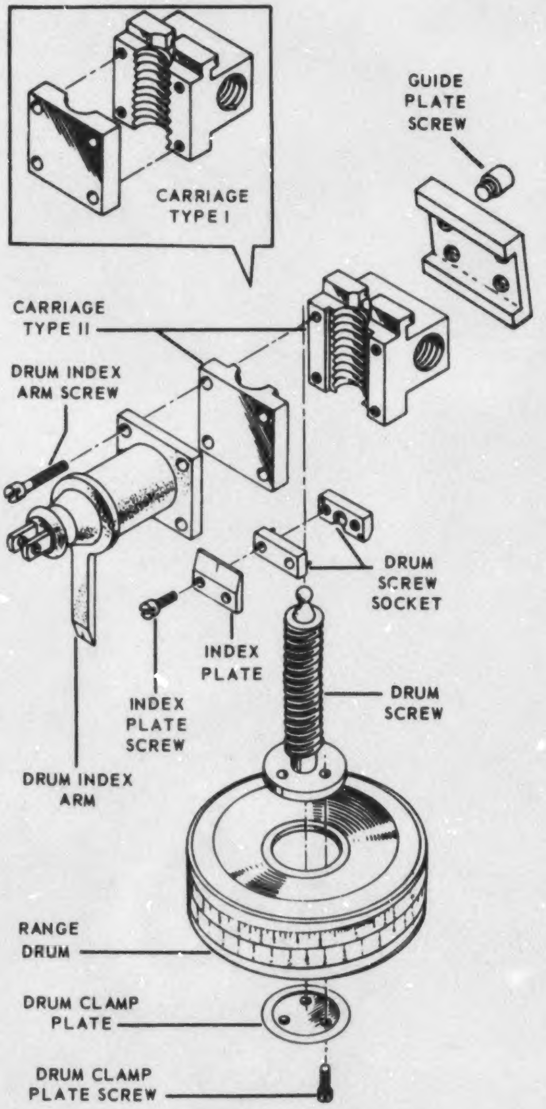
A small two power Galilean telescope is screwed into a bracket attached to the frame. With this slight magnification, there is a better view of the target.

A rectangular index mirror (1 1/4 by 1 1/2 inch) is mounted on, and turns with, the index arm. The horizon mirror (1 by 3/4 inch) is held in the lower half of an open frame which is mounted on a turntable attached to the stadimeter frame. Both the index and horizon mirror can be tipped slightly fore and aft from vertical, and the rotating base of the horizon mirror allows for parallelism adjustment of the two mirrors.

Since the stadimeter is a split image rangefinder, one line of sight from the target passes through the open half of the horizon mirror frame directly to the telescope. The other line of sight from the target strikes the movable index mirror, reflects to the horizon mirror, and is directed to the telescope.

The index arm with height scale pivots on a tapered male bearing within a matching female bearing held in the stadimeter frame. To maintain the limited accuracy of this instrument, the pivot axis must be perpendicular to the plane of the frame. A leaf spring bears against the index arm to hold it in position. Wear or damage to the index arm will reduce accuracy of ranges taken.

The complete carriage assembly is shown in figure 10-36. The carriage is held snugly in the stadimeter frame with just enough clearance to allow it to move smoothly up and down the frame when the carriage screw is turned. Looseness between the carriage and carriage screw is unimportant, but looseness of the carriage in the frame or between the drum screw and split halves of the carriage will cause inaccurate range readings.



137.577

Figure 10-36.—Stadimeter carriage assembly.

REPAIR AND ADJUSTMENT

The most serious casualties that can occur to a stadimeter are:

- Any shifting of the male and female index arm bearings from an axis perpendicular to the frame.

- Bending of the index arm.
- Bending or warping of the stadimeter frame.

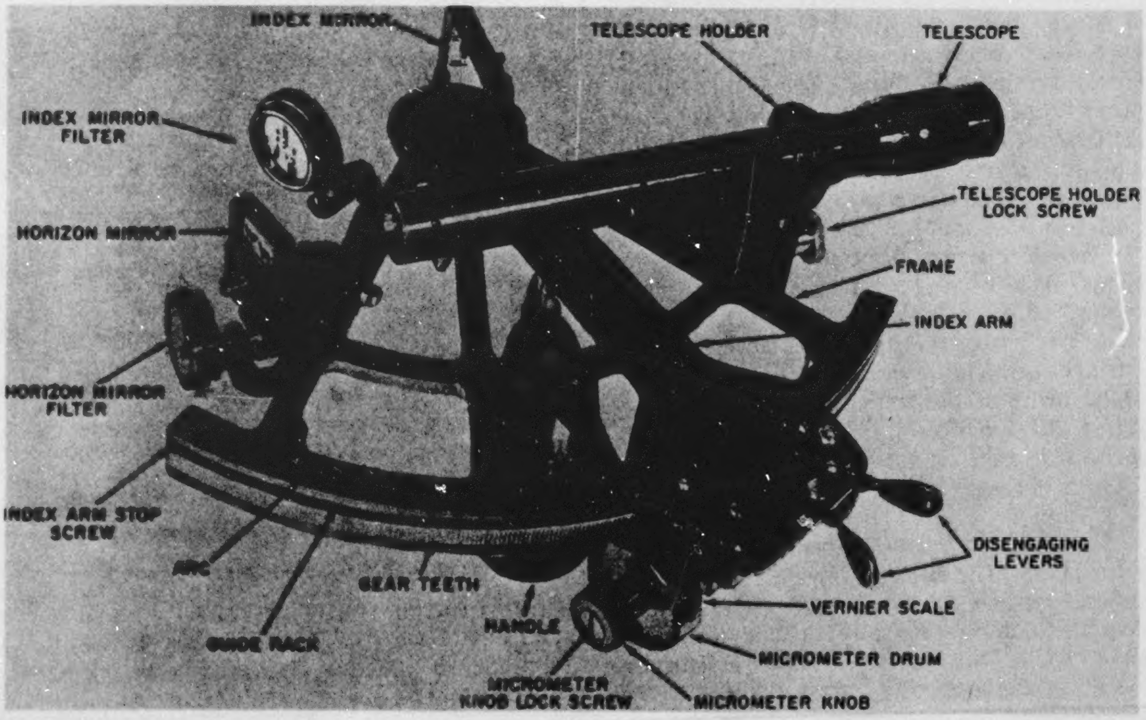
The index arm, with a matched set of bearings, can be replaced. However, if the frame is warped, you may have to survey the instrument.

For this instrument to function properly, the frame must be perfectly flat and true, the mirrors must be properly aligned, slop between the carriage and frame and between the carriage and drum screw must be eliminated, and the index arm must be parallel with the slot in the frame when the range drum is set at infinity. Parallelism between the index arm and carriage guide slot is measured with a dial indicator. Allowable error is ±.0005 inch. Any variation over this tolerance is corrected by scraping the high spots on the index arm.

Complete overhaul procedures for the stadimeter are contained in NAVSHIPS 250-624-6.

SEXTANT

The sextant is a hand held navigation instrument somewhat larger, and much more accurate, than the stadimeter. As you can see in figure 10-37, the sextant and stadimeter share some basic features. Namely, the application of two mirrors, a movable index arm, and a low power telescope. There the similarity ends. The stadimeter measures a range, when the height of the object is known, with limited accuracy; the sextant measures the angle above the horizon of a celestial body. The angle is read in degrees,



29.268

Figure 10-37.—David White endless tangent screw (ETS) sextant.

minutes, and tenths of minutes, and the exact time of the sighting is recorded. Then the navigator consults a nautical almanac to plot the ship's position. A good navigator, with a properly adjusted sextant, can pinpoint a ship's position anywhere on the surface of any existing body of water within one-quarter mile.

The David White sextant (fig. 10-37) is representative of other sextants manufactured by Pioneer, Bendix, and Weems & Plath. All four perform similar functions with slight mechanical variations. Once you have overhauled one type, you will have no difficulty with the others.

CONSTRUCTION FEATURES

The heart of a sextant is the index arm female center bearing, mounted in the frame. This bearing must be perpendicular to the frame and located at the exact geometric center of the arc of the frame. The manufacturer positions the female center, using some very sophisticated equipment. You should NEVER remove the female center from a sextant because you will not be able to replace it in the correct position.

Also mounted on the frame is an adjustable telescope holder and a bracket which holds filters and the adjustable horizon mirror mount.

The edge of the frame arc is machined with a guide rack groove to allow free movement, without play, of the index arm–and a series of gear teeth, one for each degree marked on the arc.

The mechanism that holds and moves the index arm is shown in figure 10-38. The male center bearing is not shown. All components of the index arm and worm frame assembly are carefully lapped and fitted to provide smooth action and to eliminate slop.

You can move the index arm to any position on the arc by grasping the disengaging lever to pivot the worm screw away from the gear teeth on the sextant arc. Then swing the index arm to the rough position desired and release the disengaging levers. Spring tension holds the worm screw in mesh with the rack teeth. A flat spring bears against the end of the worm shaft to prevent end thrust.

Turning the micrometer drum one revolution (60 minutes) will advance the index arm one degree. Partial revolutions are read opposite an index mark, and a vernier scale further refines the reading to indicate tenths of minutes (one-tenth of a minute is six seconds).

Study figure 10-39, which gives two sample sextant readings. In part A the reading on the arc is 13 plus (at the index mark); the 0 mark on the vernier scale is between 16 and 17; and the first mark on the vernier which coincides with a mark on the drum is 7 on the vernier scale; so the reading is 13°16.7′. The reading in part B of figure 10-39 is 55°25.2′.

REPAIR AND ADJUSTMENT

A preliminary decision must always be made concerning the feasibility of repair of an instrument. The purpose of a predisassembly inspection is to determine whether the instrument should be repaired or surveyed and salvaged, and, if repair is the decision, the extent of disassembly required.

Some of the things to check when giving a sextant a predisassembly inspection include:

- Condition of silver on mirrors.
- Corrosion and failure of protective finishes.
- Evidence of unauthorized tampering and disassembly.
- Appearance, finish, and condition of parts in the sextant assembly. Examine scale markings for legibility.
- Cleanliness and physical condition of the telescope assembly. If mounted, remove the telescope from its sliding bracket before you make this test.

NOTE: Be certain the diopter scale reference mark is at the top when you mount the sextant telescope in the sliding bracket.

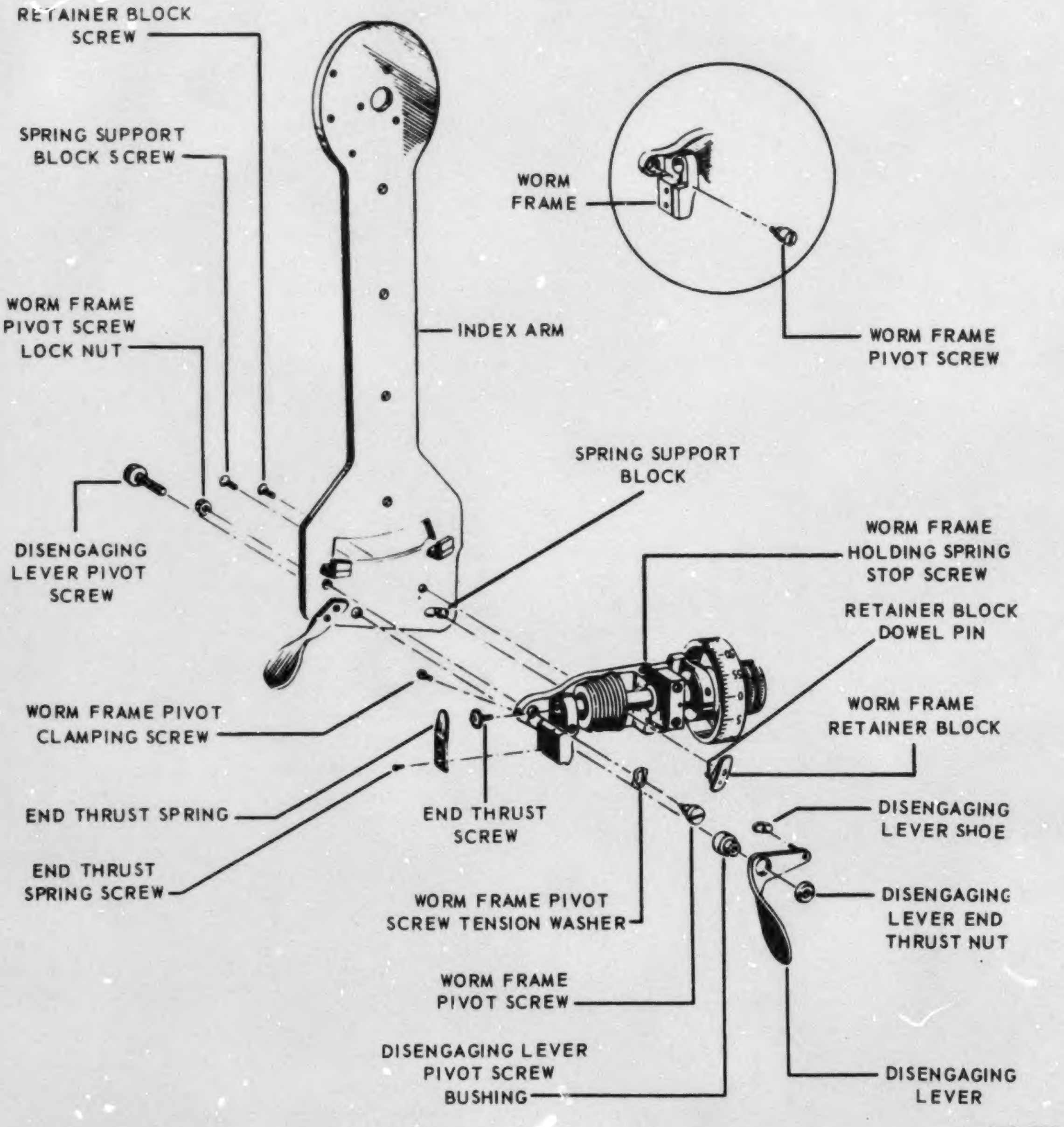
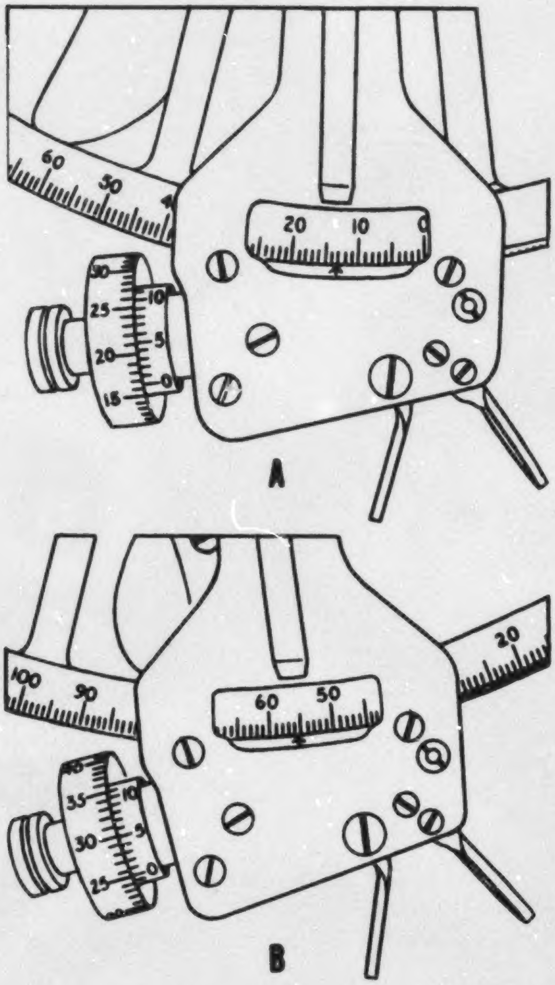

RETAINER BLOCK SCREW
SPRING SUPPORT BLOCK SCREW
WORM FRAME PIVOT SCREW LOCK NUT
DISENGAGING LEVER PIVOT SCREW
INDEX ARM
WORM FRAME
WORM FRAME PIVOT SCREW
SPRING SUPPORT BLOCK
WORM FRAME HOLDING SPRING STOP SCREW
RETAINER BLOCK DOWEL PIN
WORM FRAME RETAINER BLOCK
WORM FRAME PIVOT CLAMPING SCREW
END THRUST SPRING
END THRUST SCREW
END THRUST SPRING SCREW
DISENGAGING LEVER SHOE
DISENGAGING LEVER END THRUST NUT
WORM FRAME PIVOT SCREW TENSION WASHER
WORM FRAME PIVOT SCREW
DISENGAGING LEVER PIVOT SCREW BUSHING
DISENGAGING LEVER
137.578

Figure 10-38.—Index arm and worm frame assembly.

- Action of the focusing ring. It should be smooth over the entire diopter scale range, but it should be fairly tight.

- Polaroid filter assemblies. There should be no cracks or chips, cloudiness, or dark spots caused by dirt or moisture between the individual glasses of each filter.

NOTE: Polaroid filters must have a protective coating on their edges.



29.268(69)
Figure 10-39.—Examples of sextant readings.

- Rack guide slot. The index arm should move freely over the entire sextant frame. If you feel any binding, examine the guide slot with an eye loupe to check for burrs.

- Endless tangent worm and arc gear teeth. A sextant's accuracy also depends upon faultless engagement of the worm thread with the arc gear teeth. Carefully dress down any burrs or nicks to prevent binding and incorrect readings.

NOTE: Do NOT lubricate the worm thread and arc gear teeth. Lubricants pick up dust and other foreign particles which destroy accuracy.

Collimation of the sextant is relatively easy. The index arm and micrometer drum are mechanically set to read 0°0′, then the index and horizon mirrors are adjusted until they are perpendicular to the plane of the arc and parallel to each other. Complete overhaul information for the sextant is contained in NAVSHIPS 250-624-10.

OOD AND QM SPYGLASSES

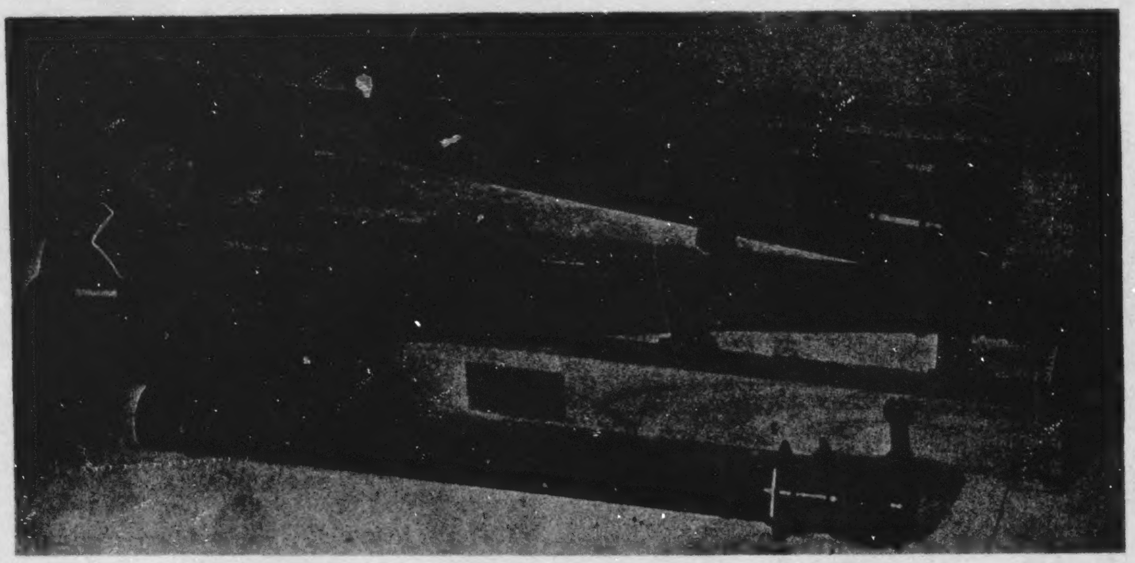
The OOD and QM spyglasses are hand held, straight line of sight, simple terrestrial telescopes. Figure 10-40 shows two variations of the QM glass and one OOD glass. These instruments are basically the same, except for the larger, longer focal length objective used in the QM glass. To account for varying focal lengths between replacement objective lenses, the objective mount of the QM glass has various spacers on each side of the lens. The objective lens of the OOD glass uses no spacers. Characteristics of the two instruments are as follows:

	OOD	QM
Magnification	10X	16X
True field	5°30′	3°30′
Apparent field	55°	56°
Eye distance	29.0 mm	28.0 mm
Exit pupil	3.5 mm	4.0 mm

CONSTRUCTION FEATURES

The eyelens, objective lens, threaded external tube sections, and setscrews are sealed with sealing compound to exclude moisture from the inside of the instrument. Focusing is by a spiral keyway arrangement which is lubricated with medium-heavy grease to assist with sealing.

A series of diaphragms is located permanently in the body tube to control



37.3

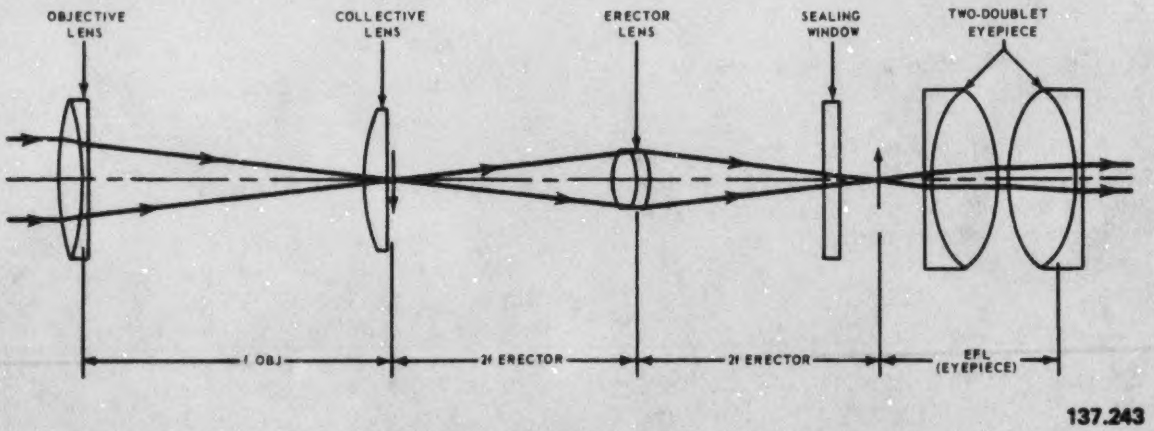
Figure 10-40.—An OOD spyglass and two QM spyglasses.

aberrations and prevent stray light. An adjustable diaphragm is mounted in the eyepiece draw tube to control aberrations and frame the final image plane.

Except for the objective lens, all optics are mounted in tube sections which thread together. Figure 10-41 shows a schematic of the optical system (not drawn to scale).

The positive achromatic doublet objective lens forms a real, inverted, diminished image, just beyond the rear surface of the collective lens.

The convex-plano collective lens gathers marginal rays of light, which would otherwise be lost, and directs them to the erector. By using a



137.243

Figure 10-41.—Optical elements for OOD and QM spyglasses.

collective lens in this position, you can obtain a fairly good field of view with a bright image.

A doublet erector lens is located approximately two focal lengths from the objective image plane. The greatest curvature of this lens is on the outer surface of the negative element, which faces the eyepiece. The erector forms a real, diminished, erect image within the focal length of the eyepiece.

A plano-parallel sealing window is shown in figure 10-41, located within the back focal distance of the erector. Most spyglasses you will work on have had this window removed.

Spyglasses use a two-doublet eyepiece, as shown. The eyelens is slightly smaller than the field lens, and the rear edge is beveled to provide space for sealing compound. The eyepiece presents a virtual, enlarged, erect image of a target to the observer.

Two gassing screws on the telescope body are used to purge these instruments, since they are not designed to hold pressure. One screw is located at the forward end of the eyepiece mount support tube, the other is behind the objective.

DISASSEMBLY

Prior to disassembly, check and inspect the QM and the OOD spyglasses in the same manner as for any other optical instrument. Write your findings on an inspection sheet and proceed with the disassembly, or consult your shop supervisor for advice concerning overhaul of the instruments.

1. Remove the setscrew which secures the eyepiece mount support tube in the body tube (fig. 10-42). Then unscrew the eyepiece mount support tube and pull it from the body tube.

2. Remove the setscrew which secures the eyepiece mount to the eyepiece mount support tube and unscrew and separate the eyepiece mount from the eyepiece mount support tube (fig. 10-43).

137.244

Figure 10-42.—Releasing the eyepiece mount support tube setscrew.

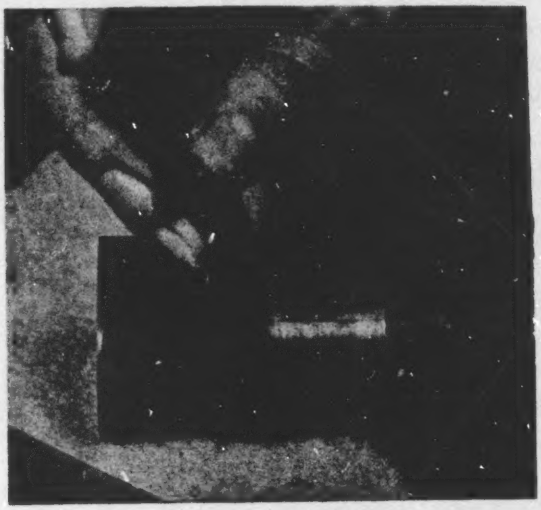
137.247

Figure 10-43.—Removing the eyepiece mount from the eyepiece mount support tube.

3. The knurled focusing ring is held on the eyepiece mount so it can be rotated to focus, but unwanted end play is prevented by two threaded rings. One acts as a retainer for the focusing ring and the other is a lockring for the retainer. Remove the setscrew from the lockring (fig. 10-44). Unscrew the lockring and then the retainer ring from the eyepiece mount. Notice that these two rings are not identical. The

137.248

Figure 10-44.—Removing the focusing ring lockring screw.



137.250

Figure 10-45.—Removing the focusing key screws.

137.252

Figure 10-46.—Removing the diaphragm lockring.

lockring has a bevel on each side and the retainer ring has only one bevel. You may need to use a grip wrench to remove the lockring.

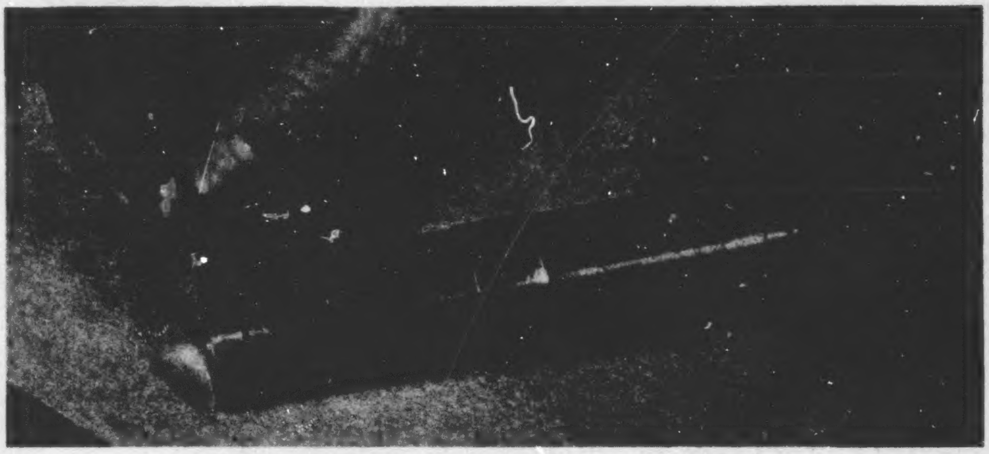
4. Unscrew the eyepiece cap from the eyepiece drawtube, and slip off the lock and retainer rings.

5. Remove the knurled focusing ring by rotating it counterclockwise to disengage it from the focusing key, then slide it from the eyepiece mount.

6. Remove the focusing key. It is aligned with two dowel pins and secured with two screws. After removing the screws (fig. 10-45), lift the focusing key from the longitudinal slot with a pair of tweezers. The dowel pins should come out with the focusing key; if they do not, remove them from the eyepiece drawtube with a pair of tweezers. The drawtube is now free within the eyepiece mount; remove it by pulling straight out.

7. With an adjustable retainer ring wrench, loosen the diaphragm lockring (fig. 10-46) just enough so that it turns freely. Do not use the wrench to remove the lockring completely from the drawtube; the wrench may damage the fine threads on the inner wall of the drawtube. Use a pegwood stick to remove the lockring. Measure and record the distance the diaphragm is in the drawtube. (NOTE: The position of the diaphragm is very important; it controls chromatic aberration.) Remove the diaphragm in the same manner you remove its lockring.

8. Remove the lockring which secures the eyepiece lenses and their spacer.



137.253

Figure 10-47.–Removing the collective-erector support tube setscrew.

CAUTION: When you remove the lockring, the field lens and spacer are loose and can easily fall out. This lockring is almost the same diameter as the diaphragm lockring; do not get these rings mixed.

9. With a piece of lens tissue on the plano surfaces of the field lens and the eyelens, turn the eyepiece drawtube over and let the field lens and spacer slide out into your hand. The rear surface of the eyelens is sealed, so apply a little pressure with your thumb to break the seal. The clearance between the lenses and the inner wall of the drawtube is so small that you need to press out the lenses. When you remove the lenses and spacers from the drawtube, mark them to indicate the direction they face in the drawtube. There is only one correct way for them to fit when assembled. Wrap the lenses in lens tissue and stow them in a safe place, away from the metal parts of the instrument.

10. Remove the screw which secures the collective-erector mount support tube in the eyepiece mount tube (fig. 10-47) and pull straight out on the tube to remove it from the eyepiece mount.

11. Loosen the collective lens mount lockring and unscrew the collective lens mount from the support tube. Remove the collective lens lockring and the collective lens. Then wrap it in lens tissue. NOTE: If this lens has pits, scratches, or chips, replace it. The lens is near the focal plane of the objective lens; any defect on the collective lens is very apparent in the field.

12. Remove the erector lens mount lockring from the support tube. Be careful to prevent damage to the fine threads on the inner wall of the support tube. Remove the erector lens mount from the support tube. (NOTE: The erector lens mount may come out of the support tube in reverse of that shown in figure 10-48. To facilitate collimation, this mount can be mounted either way.) Remove the erector lens

137.254

Figure 10-48.–Removing the erector lens mount from its support tube.

lockring and then the erector lens. Note that the exposed surface of its negative element has the greatest amount of curvature. Mark the lens and wrap it in lens tissue.

13. Loosen and remove the sealing window lockring in the eyepiece end of the eyepiece mount support tube. The window is sealed with sealing compound. If necessary, apply heat to soften the wax and use a suction cup pressed tightly against the window to help break the seal.

14. Loosen the objective mount of the OOD spyglass with a grip wrench and remove the mount. Now remove the objective lockring and the objective lens from the inside of the mount. (NOTE: No setscrew secures the objective mount to the body tube. The objective mount of a QM spyglass is part of the body tube and cannot be removed. The lockring, spacers, and objective lens are removed from the front of the body tube.)

15. Remove the two gassing screws and be sure both gassing screw orifices are free of obstructions.

You have now completed disassembly of the QM or OOD spyglass.

REPAIR, REASSEMBLY, AND COLLIMATION

OOD and QM spyglasses usually need refinishing due to mistreatment and salt damage. Follow the procedures outlined in Chapter 7 if you repaint or cement lenses.

Correct defects noted during disassembly which were not apparent when you inspected the instrument. Pay particular attention to threaded support tube sections, lockring threads, and retainer ring threads. Remove any nicks or damage with thread chasers. Clean these components with a clean brush and fit them together to be sure they turn smoothly before cleaning and mounting optics.

Before replacing the lenses in the eyepiece drawtube, assemble the focusing mechanism to set 0 diopters at mechanical midthrow. At this time you also remove any play between the focusing key and spiral keyway.

With the focusing ring retaining ring and lockring properly tightened to allow the focusing ring to turn without end play, turn the focusing ring slightly in both directions and observe the drawtube. If the drawtube moves when the focusing ring is turned, the focusing key is correct. If any play is evident, you will have to spread the ends of the focusing key by tapping lightly with a prick punch (peening). A very slight amount of peening is usually sufficient; do not overdo it. Fit and try until the focusing action is smooth and positive.

To check mechanical midthrow, turn the focusing ring to move the drawtube all the way in, then measure the height of the assembly. Now turn the drawtube all the way out and measure again. Position the drawtube halfway between these two measurements and observe the alignment between the 0 mark on the diopter ring and the index mark on the focusing ring. If they are not perfectly aligned, you will have to carefully drill and tap a new hole for the diopter ring lockscrew.

Disassemble the focusing mechanism again and be sure the components are clean. Place a thin bead of sealing compound around the eyelens seat and replace the two lenses, spacer, and lockring. Tighten the lockring enough to ensure that the eyelens is sealed and seated properly. Replace the diaphragm in its original position. To check for proper placement of the diaphragm, look through the eyelens and look at the edge of the diaphragm. You will notice a fringe of yellow around this edge if the diaphragm is located correctly when the eyepiece is set to 0 diopters. If not, turn the diaphragm in or out until this condition is met, then install the diaphragm lockring.

Now reassemble the collective and erector lenses and the various internal tube sections. Lubricate and reassemble the focusing mechanism, then seal and install the eyepiece mount on the eyepiece mount support tube.

NOTE: If a sealing window is used, replace and seal it prior to installing the eyepiece mount.

Replace and seal the objective lens and mount of the OOD spyglass. Do not seal the objective of the QM glass at this time. You may need to reposition this lens during collimation by shifting spacers.

Place a piece of fine wire through the holes behind the collective lens, pull the wire tight, and twist the ends together to hold it tightly in position. Now screw the eyepiece mount support tube into the telescope body. NOTE: Do not seal the joint at this time.

Place the assembled telescope in V-blocks on any convenient collimator and use an auxiliary telescope set to your eye correction to check for parallax between the collimator target and auxiliary wire. Remove parallax by screwing the collective lens mount in or out of the support tube.

When you assemble the eyepiece mount support tube and telescope body after each adjustment, be sure the joint is tight. If you do not have enough movement on the collective lens mount of a QM glass, now is the time to shift objective spacers. Move the lens the same direction you want the collimator image to move; then seal the QM glass objective.

After eliminating parallax, set optical zero diopters by adjusting the erector lens mount. Use an auxiliary telescope to determine which way the final image plane must move so the image will be in sharp focus at mechanical zero diopters.

These are single erector telescopes, so you must move the erector in the opposite direction you want the image plane to move. Remember, you can reverse the erector lens and mount if necessary. Just be sure the lens is facing the right way, or you will introduce unwanted aberrations.

With parallax removed and optical zero diopters set, make sure the collective mount lockring, erector lockring, and collective erector support tube setscrew are tight. Make a final check for parallax, then remove the auxiliary wire. Now you can seal the eyepiece mount support tube and replace and seal the setscrew in the telescope body. Purge the instrument as explained in Chapter 8 and replace and seal the gassing screws.

When the instrument passes a final inspection for cleanliness, collimation, focusing action, and appearance—your work is finished.

SHIP TELESCOPE

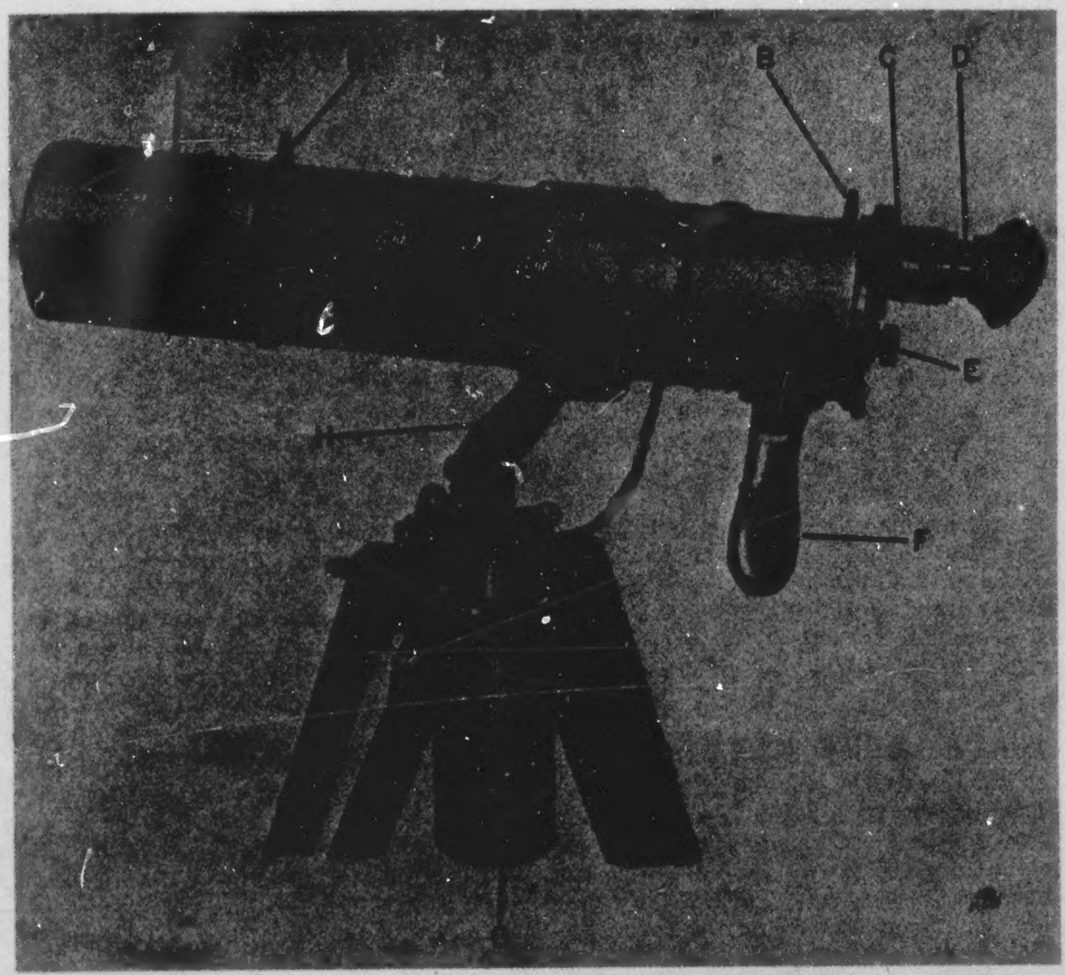
The ship telescope (fig. 10-49) is a change of power observation instrument with a porro prism erecting system. It is mounted on the open bridge of ships in a yoke that allows it to be elevated within practical limits and trained in any direction. Change of power is provided by four interchangeable eyepieces of 13X, 21X, 25X, and 32X. The 21X eyepiece is orthoscopic, while the others are Kellner types. Since this instrument is exposed to salt spray and all types of weather, all joints and lenses are sealed with sealing compound to exclude moisture. There is no provision to gas or purge the ship telescope.

CONSTRUCTION FEATURES

The optical system and basic mechanical assembly are shown in figure 10-50. These are relatively simple telescopes with few adjustments. However, you will come across some instruments in such poor condition that they will tax your skill as an Opticalman.

The objective mount is threaded externally so it can be attached to and positioned in the body tube. A lockring holds the mount in position and a sunshade screws on to the outboard side of the mount. The front sight vane functions as a lock screw for the objective mount.

Since the objective lens is too large to cement, the elements are separated by three



A. Sunshade assembly
B. Sighting vane
C. Diopter scale
D. Eyepiece assembly
E. Filter shaft knob
F. Grip handle
G. Eyepiece cover
H. Yoke assembly

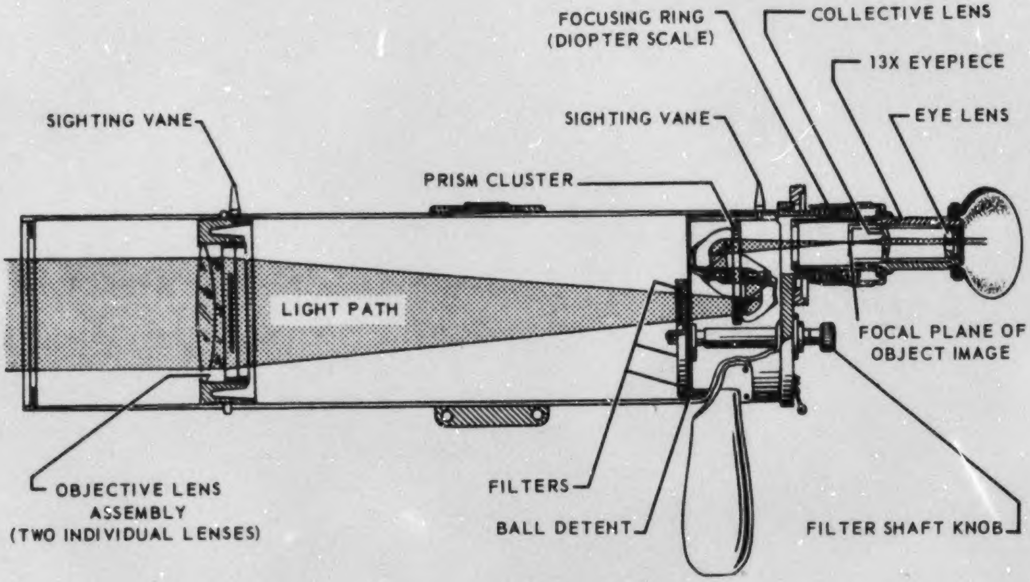
37.2

Figure 10-49.—Mark 1 Mod 0 ship telescope.

equally spaced tin foil shims .001 to .002 inch thick. A spring ring backed by a retainer ring holds the lens in the mount.

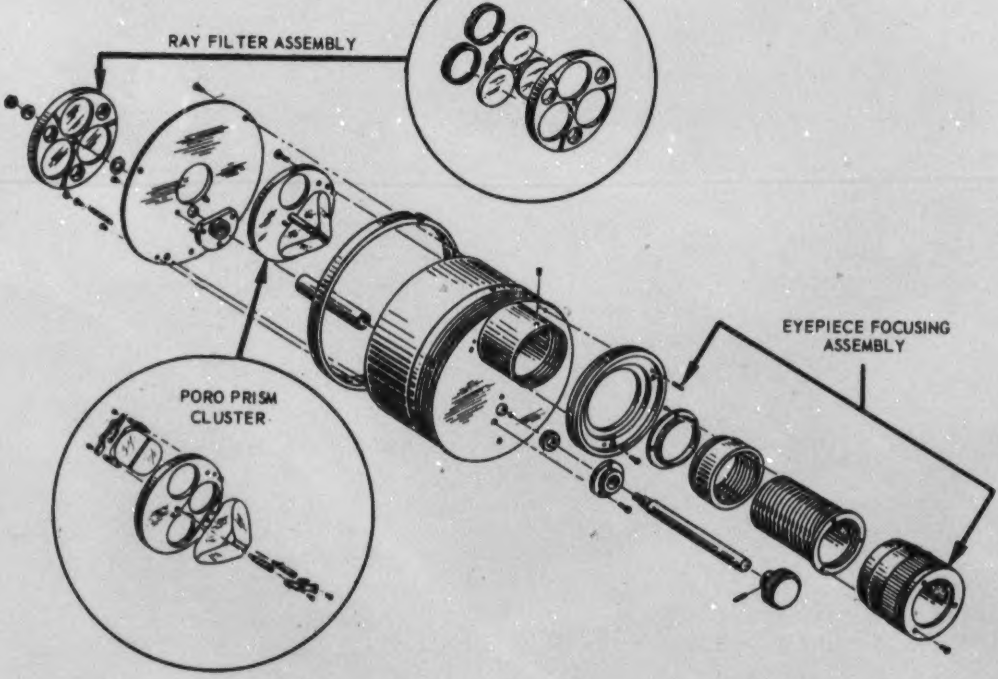
All other components of the ship telescope are mounted on a prism box which threads into the body tube (fig.10-51). A lockring holds this prism box in position and the rear sight vane serves as a setscrew.

A filter plate, controlled by a shaft through the prism box, is located within the objective focal length. A clear plano parallel compensator (to eliminate a change in objective focal



37.5

Figure 10-50.—Optical system of a Mk 1 Mod 0, ship telescope.



137.529

Figure 10-51.—Prism box, filter, and eyepiece focusing assembly—exploded view.

distance), a light blue filter, and a single dark polaroid filter are mounted in the filter plate. The polaroid filter is oriented to reduce glare when it is in the line of sight.

The porro prism cluster, as usual, can be adjusted to remove lean. Finally, the multiple lead focusing mechanism is secured to the outside of the prism box. The four matched eyepieces screw into the focusing tube so the operator can easily change them without tools.

REPAIR AND ADJUSTMENT

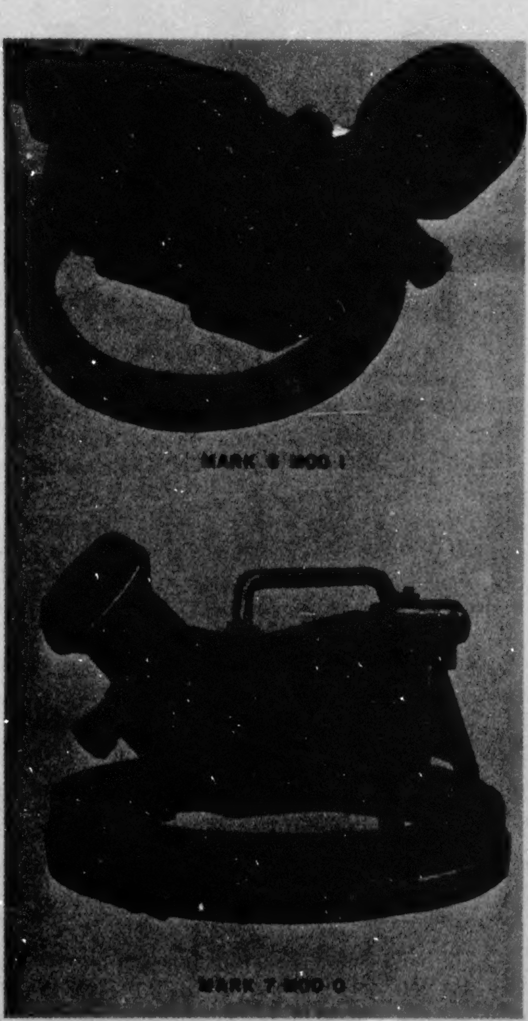
The ship telescope is mostly constructed from aluminum. Even your best efforts to seal joints may eventually fail and allow salt corrosion, making disassembly difficult. Since the sunshade and body are quite thin, you will need to make fitted wooden clamp blocks to hold the telescope securely without crushing during disassembly.

Complete overhaul and collimation instrucions are found in NAVSHIPS 250-624-3. The only unusual departure from normal repair and collimation procedures is parfocalizing the four eyepieces. Each eyepiece must focus within ±1/4 diopter of the others. To do this, machine a predetermined amount of metal from the mounting shoulder of the eyepiece(s) in error.

TELESCOPE ALIDADE

The telescopic alidade is a portable navigational instrument used by personnel aboard ship to accurately measure the bearing of distant objects. When in use, a telescopic alidade is placed over the ship's magnetic compass or gyro repeater, and the observer sees a magnified image of the target (6X) aligned with a vertical wire, combined with an image of a level vial and compass card in the upper part of the field.

The two instruments shown in figure 10-52 are identical, except for the size of the adapter ring which fits different gyro repeaters or compasses.

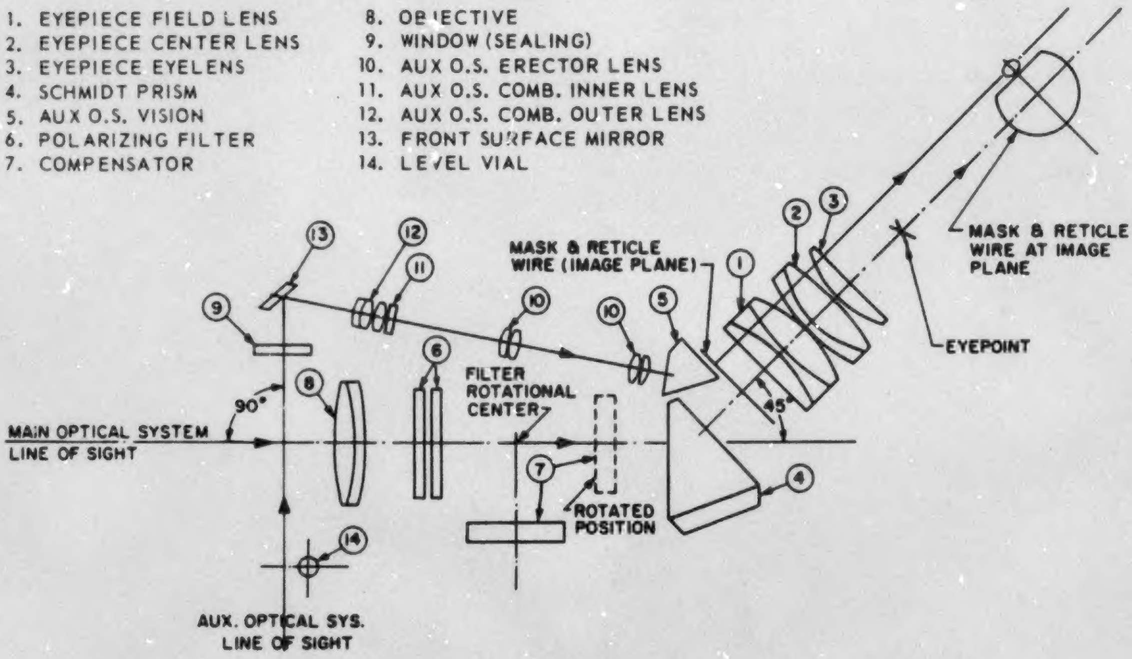


45.39
Figure 10-52.—Mark 6 and 7 telescopic alidades.

CONSTRUCTION FEATURES

The Mk 6 and Mk 7 alidades are gastight, aluminum bodied, dual line of sight instruments with an internal focusing eyepiece which focuses the main and auxiliary optical systems. The optical schematic is shown in figure 10-53.

The main optical system consists of an objective lens, a filter assembly, a Schmidt prism



137.535

Figure 10-53.–General optical arrangement Mk 6 and 7 alidade.

(erects the image and directs it toward the eyepiece at a 45° angle), and the eyepiece system. The filter assembly consists of a fixed and movable polaroid and a clear compensator. A large knob on the right side of the alidade drives the filter assembly (in or out of the line of sight), while a smaller knob through the center of the large knob controls polaroid density.

The objective lens is adjustable along the optical axis to correct for parallax between the target and crosswire.

The Schmidt prism is bonded to a post which is held to the prism mounting plate with three screws. The screws have enough clearance so the prism post can be adjusted up or down, fore and aft, or rotated slightly in a vertical plane.

The auxiliary optical system consists of a sealing window (9), a front surface aluminized mirror (13), an inner and outer objective (11, 12), two identical erector lenses (10), and the auxiliary system prism.

The auxiliary mirror is bonded to a threaded plug which screws in or out of the alidade body. This allows you to raise or lower the compass card image in the auxiliary field of view and to correct for tilt or lean in the auxiliary field.

The two objectives share a common cell, as do the erectors, and both cells are threaded for adjustment along the auxiliary axis.

The auxliary prism (5) is mounted and adjusted in the same manner as the main prism.

A metal plate and fine crosswire are mounted at the common image plane of the main and auxiliary optical systems.

The image of the level vial (14) will always be slightly out of focus since it is positioned approximately 1 inch above the compass or repeater.

REPAIR AND ADJUSTMENT

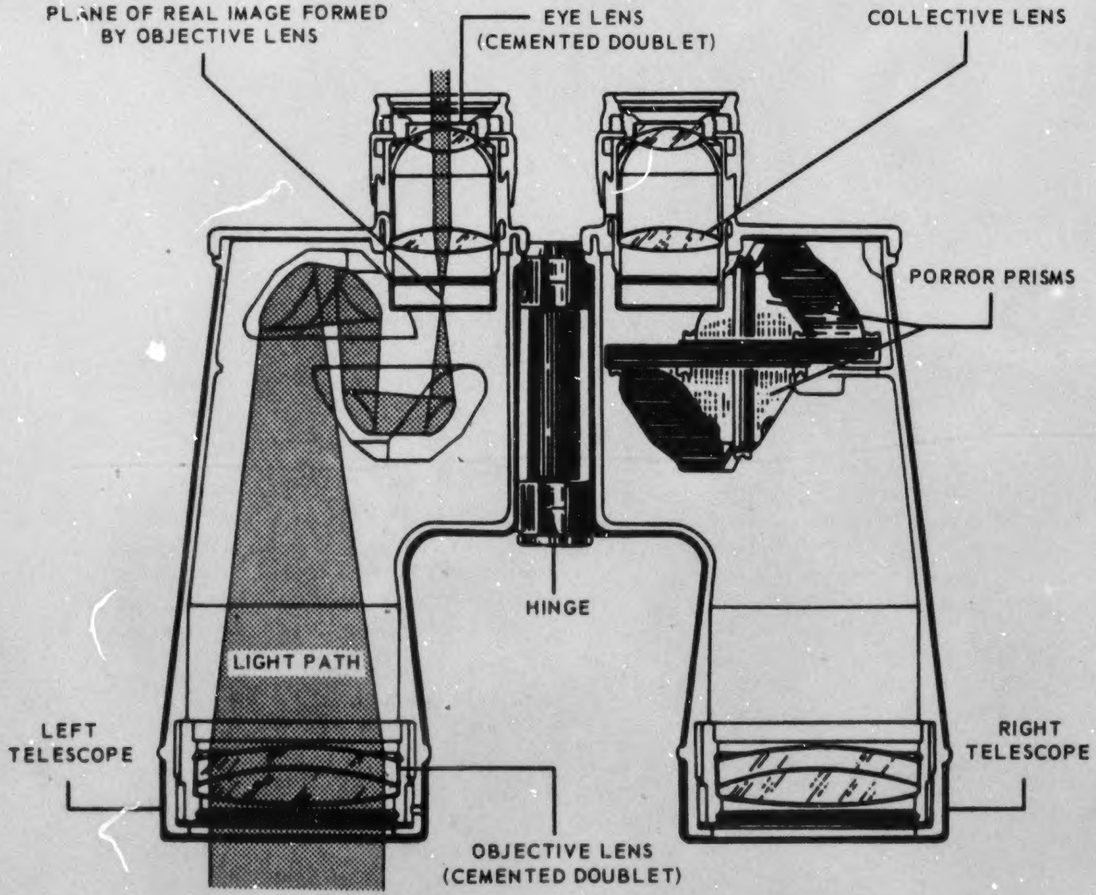
After you have acquired some experience repairing optical instruments, you will probably discover that the Mk 6 and Mk 7 alidades are made to be replaced, rather than repaired. This is unnecessarily expensive, and frustrating to a good repairman.

The complete overhaul procedure, as well as drawings and parts lists, is contained in NAVSHIPS 324-0488. Basically, collimation consists of aligning a collimating stand on the collimator (Mk 4), adjusting the main optical system, and adjusting the auxiliary optical system.

Once the instrument is collimated and sealed, you must test for leaks, dry the interior with nitrogen, and charge it to 4 psi pressure.

BINOCULARS

Everyone knows what binoculars are, but now you will learn something about them. We


PLANE OF REAL IMAGE FORMED BY OBJECTIVE LENS
EYE LENS (CEMENTED DOUBLET)
COLLECTIVE LENS
PORROR PRISMS
HINGE
LIGHT PATH
LEFT TELESCOPE
RIGHT TELESCOPE
OBJECTIVE LENS (CEMENTED DOUBLET)

137.465

Figure 10-54.—Cross section of a binocular system.

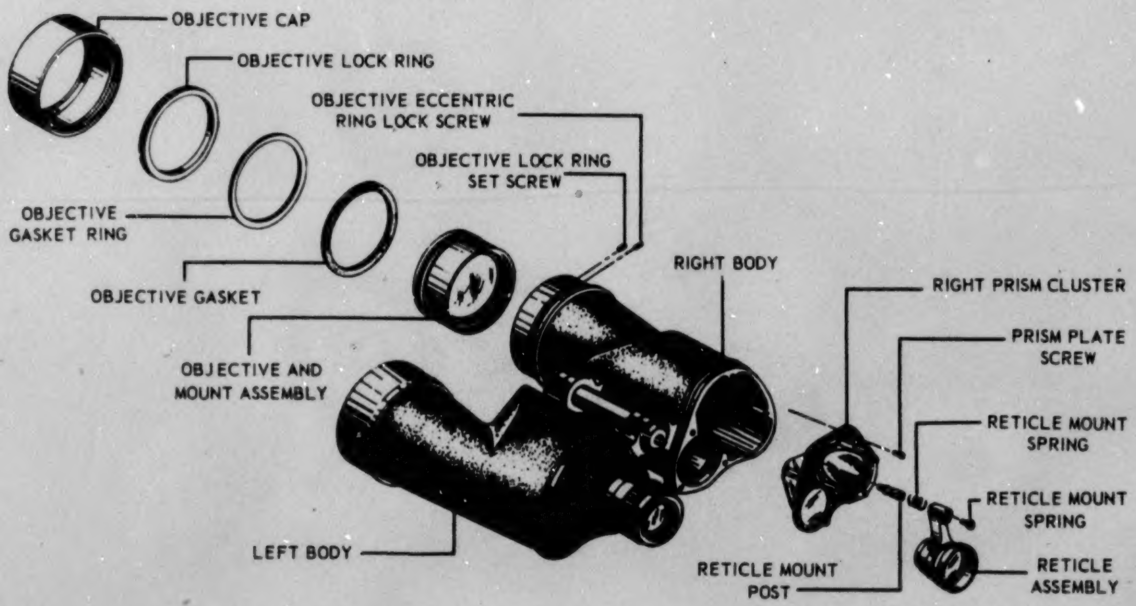
will discuss two basic types, the hand held 7 X 50 and the mounted 20 X 120. The numbers 7 and 20 refer to magnification, and 50 and 120 indicate the size of the objective lens opening in millimeters.

7 X 50 BINOCULARS

The optical system and mechanical arrangement, shown in figure 10-54, are generally common to all current hand held binoculars. In effect, there are two separate, prism erected telescopes joined by a hinge so people with different eye separations can use the instruments comfortably. 7X has been determined to be about the highest practical magnification for hand held binoculars. Any more power would cause excessive target motion, and any less would not bring out sufficient detail on the target. The 50-mm objective lens has very good light gathering ability under all weather conditions. In fact, binoculars used by the Navy can be used effectively half an hour before sunrise and half an hour after sunset. The wide separation between the objective lenses increases your effective interpupillary distance, thereby increasing your range of stereoscopic vision. (Stereoscopic vision is directly related to your ability to judge relative distance between objects.)

CONSTRUCTION FEATURES

The Mk 28 and Mk 29 binoculars are practically identical, except that the Mk 39 has a reticle mounted on the right prism plate (fig. 10-55). These two instruments are sealed against moisture by sealing compound in lens mounts and joints between body and covers, and by heavy grease on the eyepiece cell. The prism plates are mounted on lugs inside the body and



137.471

Figure 10-55.–Binocular objective and prism cluster Mk 28 and reticle assembly Mk 39.

the objective assembly slips into a recess in the front of the body.

The Mk 32 has several changes, mainly to improve sealing the instrument. It also has an objective adapter which screws into the binocular body. See figure 10-56.

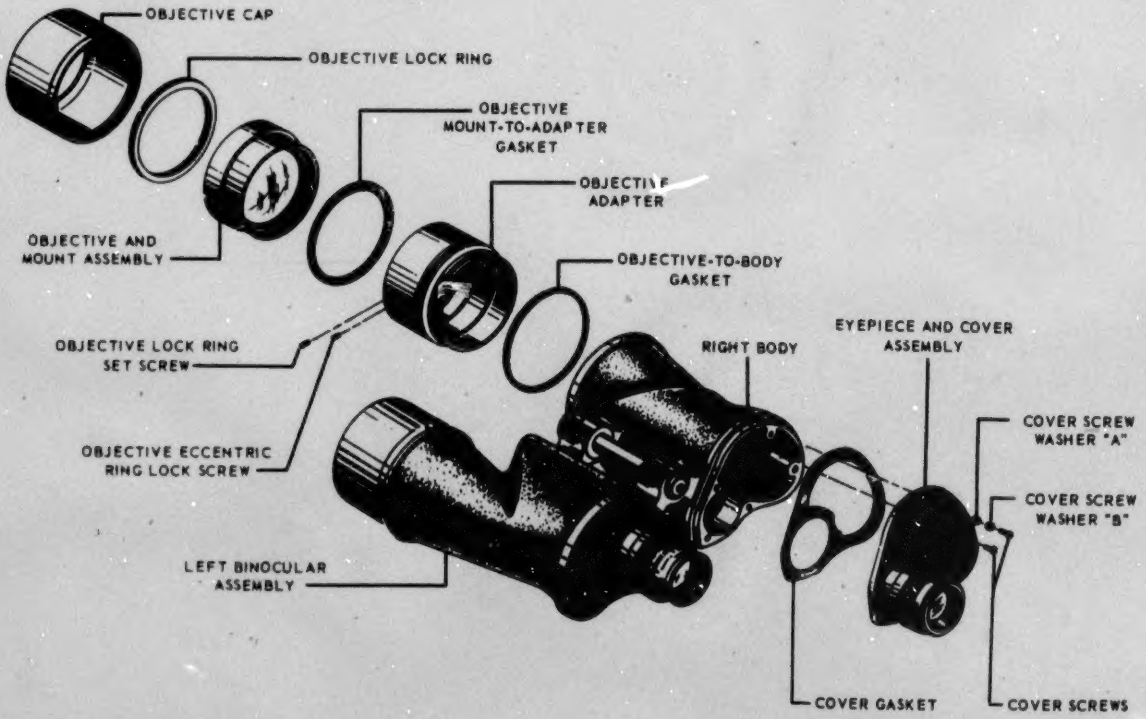
Two types of eyepiece assemblies are shown in figure 10-57. Again the major difference between the Mk 28 and Mk 39 and the Mk 32 is in the provision for sealing the instruments.

An exploded view of a prism cluster, common to the Mk 28, Mk 32, and Mk 39 is shown in figure 10-58.

The hinge is the heart of a pair of binoculars. It must operate smoothly but provide enough tension to hold the two bodies in position. It forms the mechanical axis of the instrument. Figure 10-59 shows the hinge mechanism used on the binoculars discussed so far. The tapered hinge axle is kept from turning by splines which mate with the upper left body lug. You will encounter some variations that use two dowel pins rather than splines between the hinge axle and the body lug.

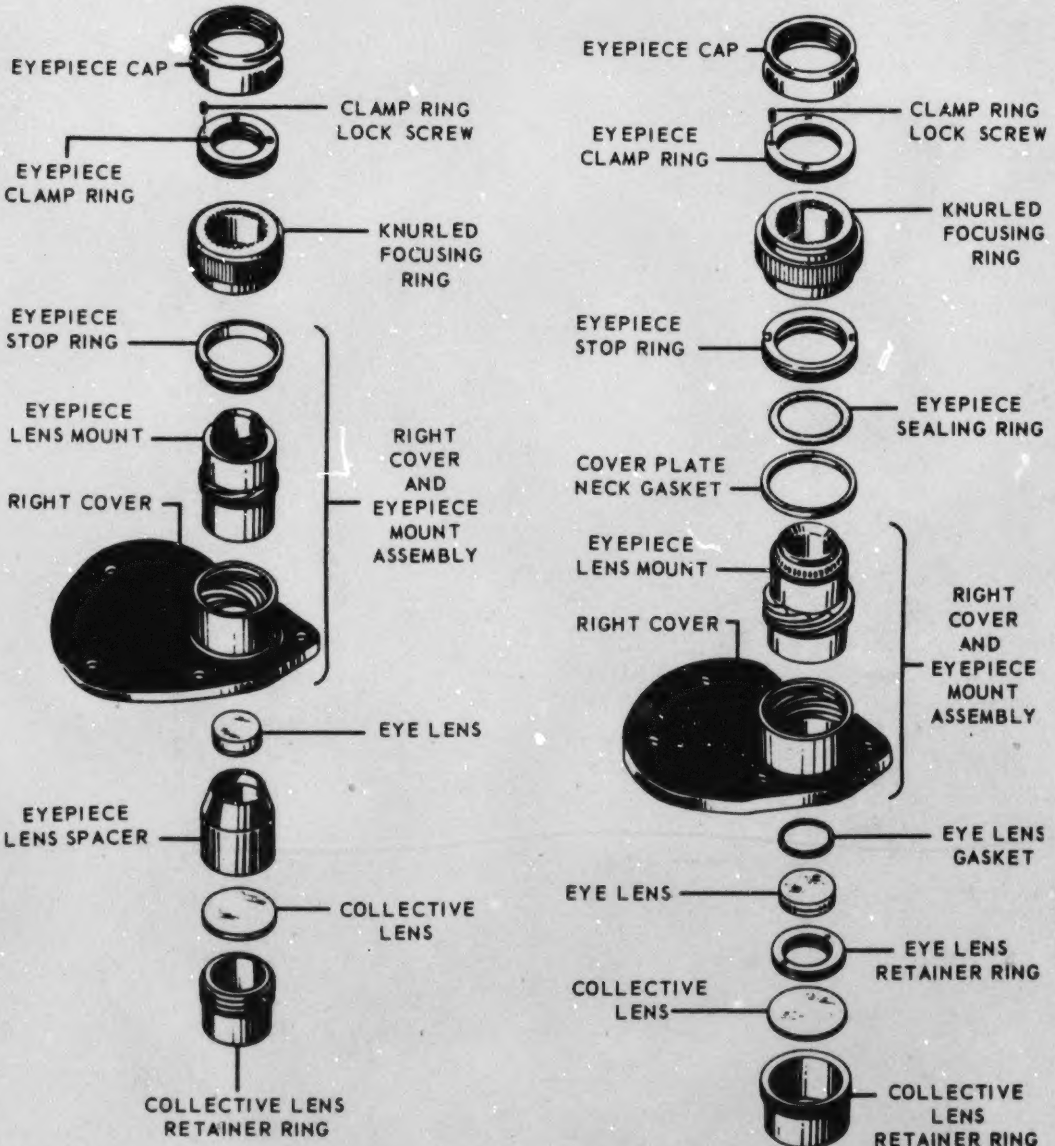
When a hinge is properly assembled, the height of the two bodies must be equal. There must be .004-inch grease clearance between the hinge axle and the tapered hinge tube (right body). These factors are controlled by the seating depth of the axle in the left body lug (upper) and various thickness hinge washers between the body lugs. The seating depth of the hinge axle is determined by the upper and lower axle screws.

Improper lubrication, incorrect adjustment, or grit or burrs on hinge components can cause problems with the hinge action.



137.579

Figure 10-56.—Exploded view Mk 32 binocular.

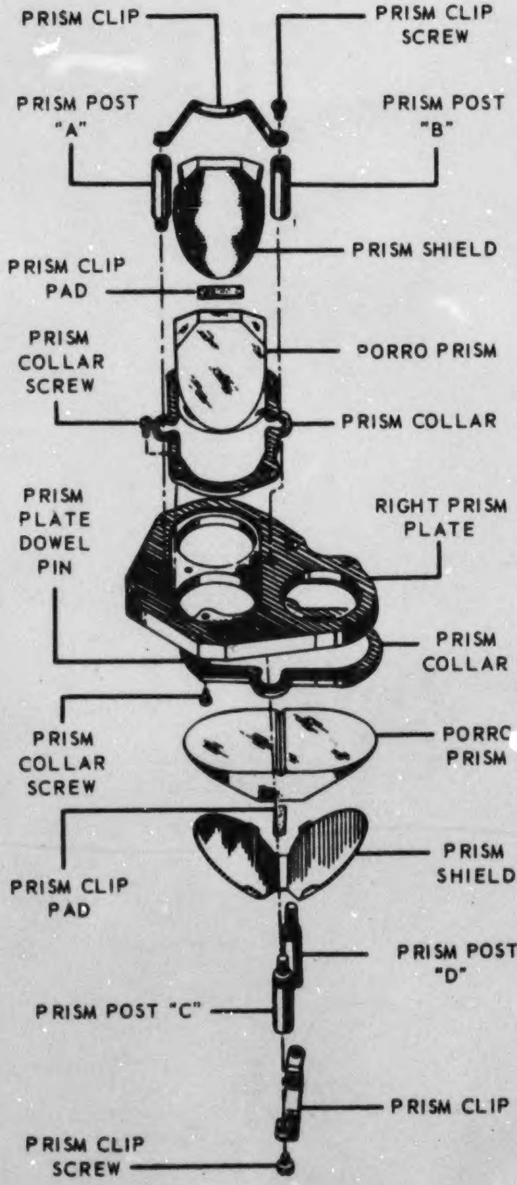


Mk 32

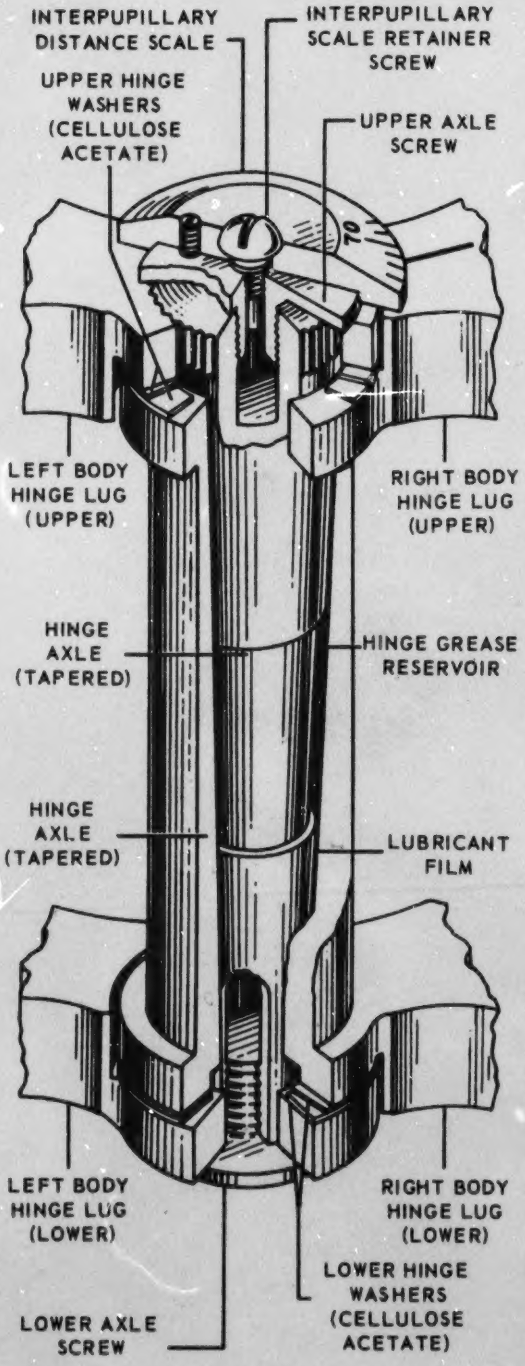
Mk 28 and Mk 39

137.580

Figure 10-57.–Eyepiece and cover assemblies Mk 28 and Mk 39 and Mk 32.



137.581
Figure 10-58.—Porro prism cluster Mk 28, Mk 32, Mk 39.


INTERPUPILLARY DISTANCE SCALE
INTERPUPILLARY SCALE RETAINER SCREW
UPPER HINGE WASHERS (CELLULOSE ACETATE)
UPPER AXLE SCREW
70
LEFT BODY HINGE LUG (UPPER)
RIGHT BODY HINGE LUG (UPPER)
HINGE AXLE (TAPERED)
HINGE GREASE RESERVOIR
HINGE AXLE (TAPERED)
LUBRICANT FILM
LEFT BODY HINGE LUG (LOWER)
RIGHT BODY HINGE LUG (LOWER)
LOWER HINGE WASHERS (CELLULOSE ACETATE)
LOWER AXLE SCREW

137.464
Figure 10-59.—Hinge mechanism (Mk 28, 32, and 39 binoculars).

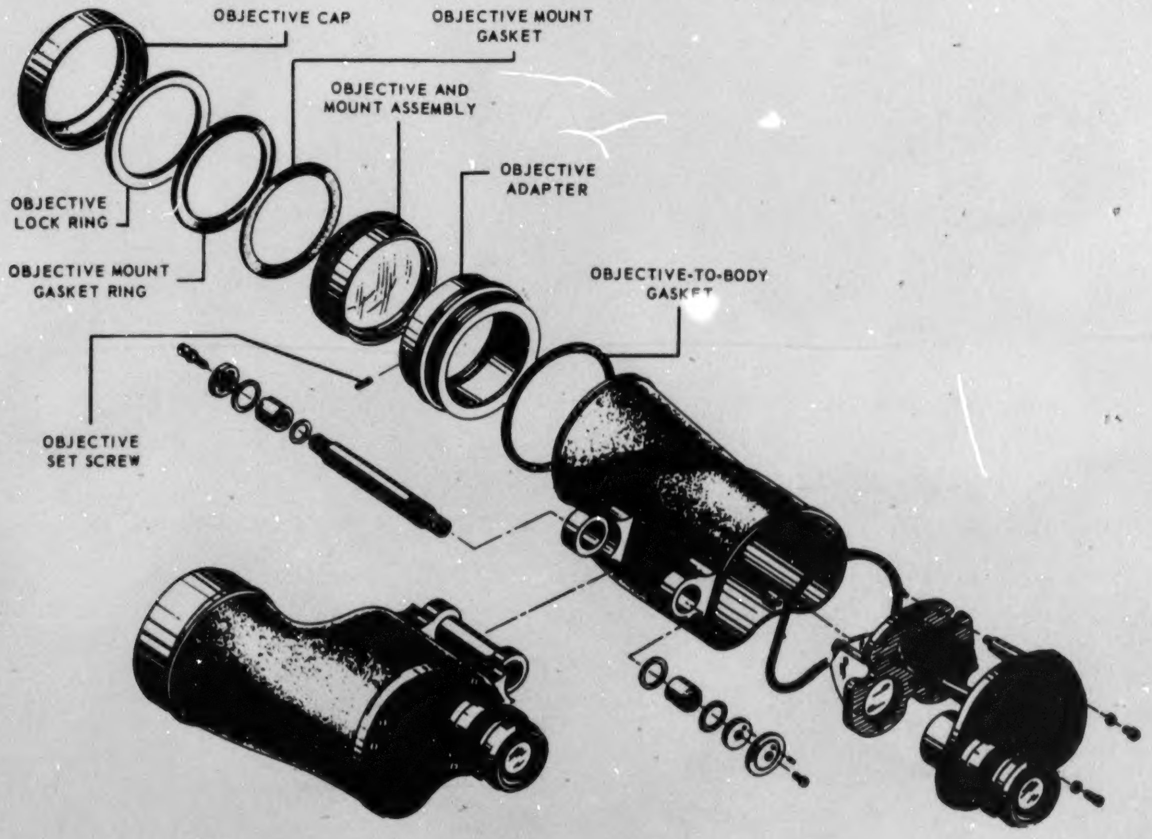
Where the Mk 28, Mk 32, and Mk 39 binoculars share some common mechanical features, the Mk 45 binocular is completely different in construction (fig. 10-60). The design of the Mk 45 makes it practically waterproof. There are many reported instances when these instruments were submerged to depths of 100 feet and did not leak.

The Mk 45 eyepiece assembly (fig. 10-61) is somewhat similar to the Mk 32, but the prism cluster (fig. 10-62) is entirely different. Also notice that the prism cluster of the Mk 45 mounts on posts on the underside of the cover plates. Four prism locating shoes are used to locate and adjust each prism.

The hinge assembly of the Mk 45 is also very different (fig. 10-63). Instead of using a tapered hinge axle, split bronze bearings screw onto each end of a straight hinge axle. As those bearings contact brass hinge thrust washers, further rotation forces them to expand and contact bearing surfaces machined in the right hinge lugs. Correct lubrication, tension adjustment, and corrosion prevention are essential to smooth operation of the Mk 45 hinge.

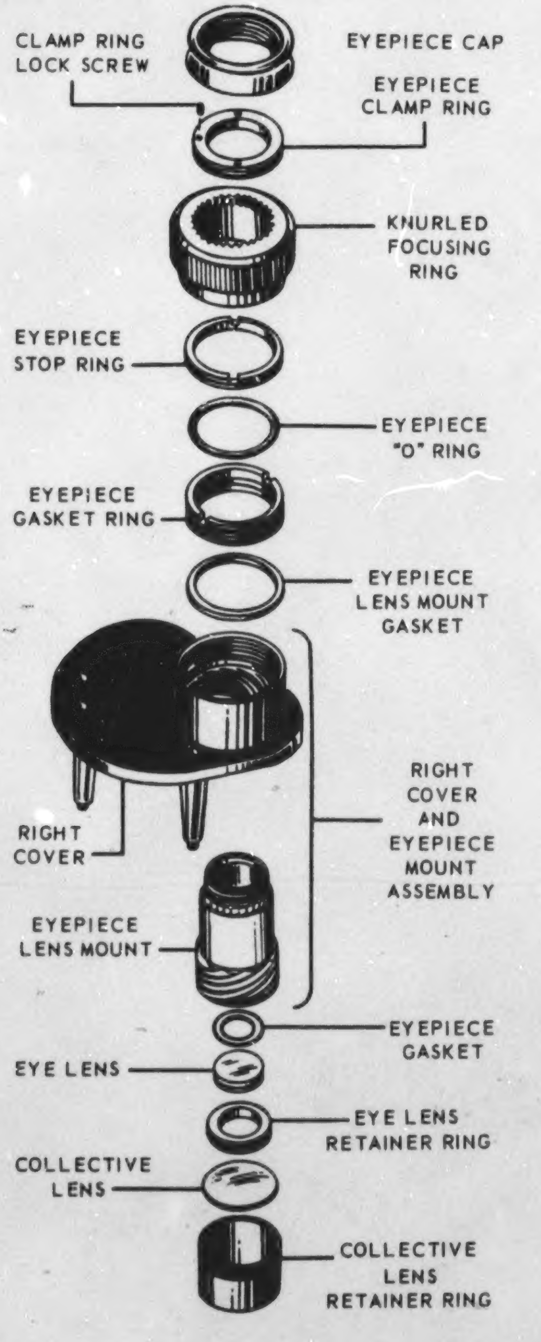
OVERHAUL

As an Opticalman, you will work on more binoculars than all other instruments combined. Some binoculars will be sent to the optical shop in excellent condition, others will be basket cases. A good casualty analysis will indicate the extent of repair and disassembly necessary. Do not disturb any more than necessary to do a



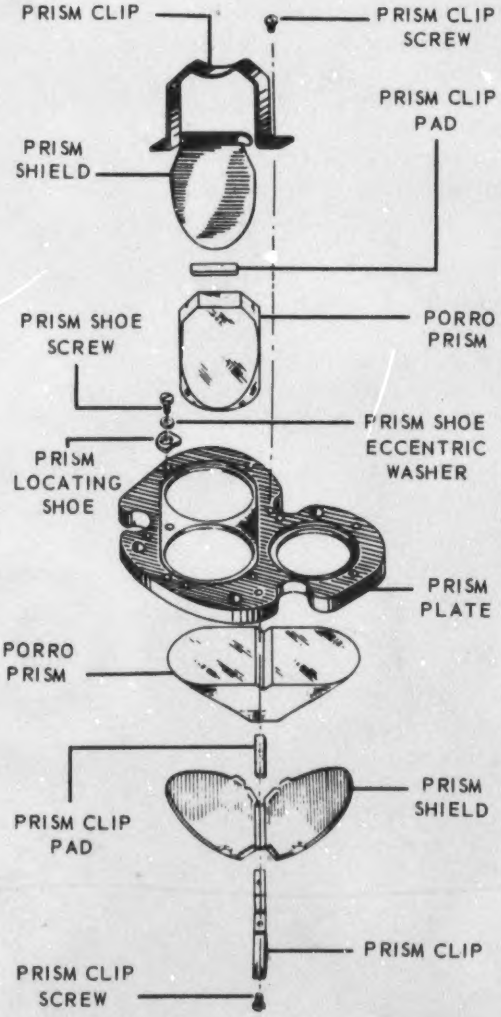
137.541

Figure 10-60.—Mk 45, 7 X 50 binocular assembly—exploded view.



137.582

Figure 10-61.—Mk 45 binocular eyepiece and cover assembly.

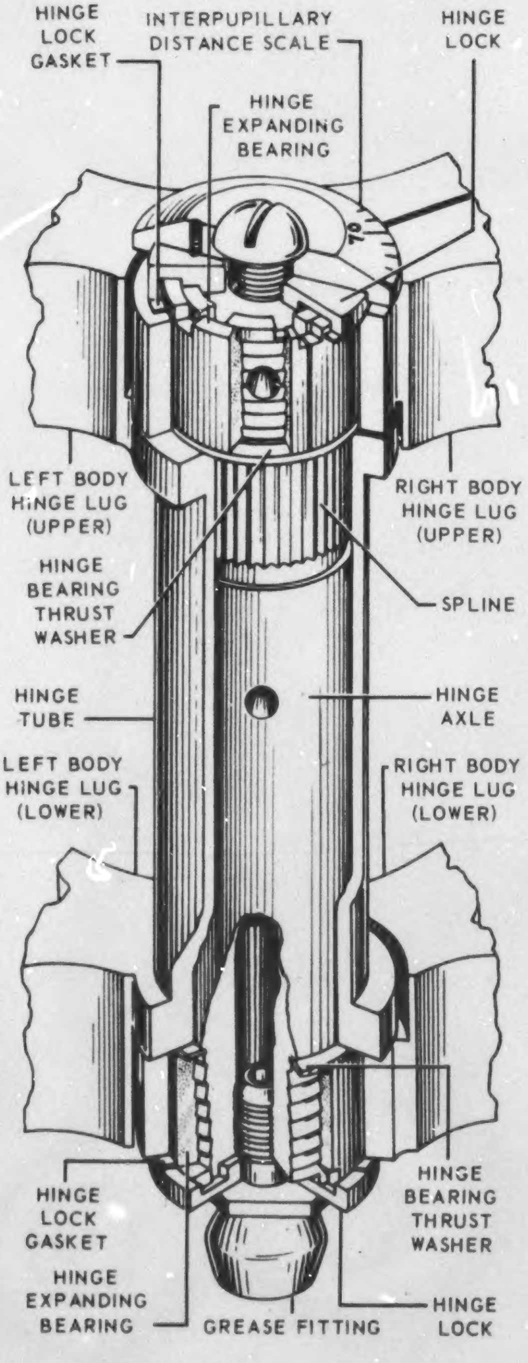


137.583

Figure 10-62.—Mk 45 binocular prism cluster.

typical outstanding overhaul. It does not make any difference whether you disassemble the objectives or the eyepiece and cover assemblies first, but save the hinge for last. Likewise, if you must completely disassemble a pair of binoculars, reassemble and adjust the hinge before installing optics.

NOTE: The hinge of hand held binoculars receives considerable wear; therefore the hinge of each pair of binoculars sent to the shop should be checked, lubricated, and readjusted.


HINGE LOCK GASKET
INTERPUPILLARY DISTANCE SCALE
HINGE LOCK
HINGE EXPANDING BEARING
70
LEFT BODY HINGE LUG (UPPER)
RIGHT BODY HINGE LUG (UPPER)
HINGE BEARING THRUST WASHER
SPLINE
HINGE TUBE
HINGE AXLE
LEFT BODY HINGE LUG (LOWER)
RIGHT BODY HINGE LUG (LOWER)
HINGE LOCK GASKET
HINGE BEARING THRUST WASHER
HINGE EXPANDING BEARING
GREASE FITTING
HINGE LOCK

137.540

Figure 10-63.–Mk 45 hinge mechanism.

Always replace gaskets, where appropriate, and never interchange optics or mechanical parts between bodies. Binoculars can be temperamental if you start switching parts, so use a compartmented parts box to keep them separated. Even with excellent quality control, dimensions of mechanical components will vary slightly, lenses will have minor focal length differences, and prisms will not always be identical. Use a lens centering instrument to check focal lengths of lenses, and make a side visual inspection to determine variations between mechanical components. The seating depth of objective lenses in their mounts can be troublesome at times, especially if different size prisms are used in each telescope.

To compare prisms for size, place them in a V-block protected by a sheet of lens tissue. The entrance/emergence face of the larger prism will be higher than the corresponding surface of the other prism. Replacing any prism in a pair of binoculars, with one of larger size, will lower the eyepiece in that telescope. The converging light from the objective has to travel further in the larger prism, therefore it comes to a focus farther from the eyepiece (see figure 10-54), and you have to turn the eyepiece in to focus the image.

Cleanliness is just as important in binoculars as it is in any other instrument. Dust or grease smudges will reduce light transmission, and these defects can be seen on the optics. The collective lens is very close to the objective image plane so any specks or lint will be magnified and very obvious. Remove grease from all lens mounts before you attempt to replace the lenses.

When you remove the eyepiece cells from the cover plates, mark the relationship between these parts so you can reassemble them in the same position–especially if focusing action is equal between them. If focusing action is not equal, try a different lead on the multiple lead thread. Eyepiece cells of the Mk 28, 32, and 39 are removed from the top. The Mk 45 should be removed from the bottom.

Apply lubrication to the eyepieces and objective eccentric rings during final assembly.

Likewise, use antiseize on cover screw threads, objective cap threads, and threads of the objective adapters (where appropriate).

COLLIMATION

Prism cluster assembly is a very important part of binocular collimation. If this is not done properly, you may not be able to collimate your binoculars without disassembling one or both clusters to find the problem. Porro prism cluster adjustments were discussed in Chapter 8.

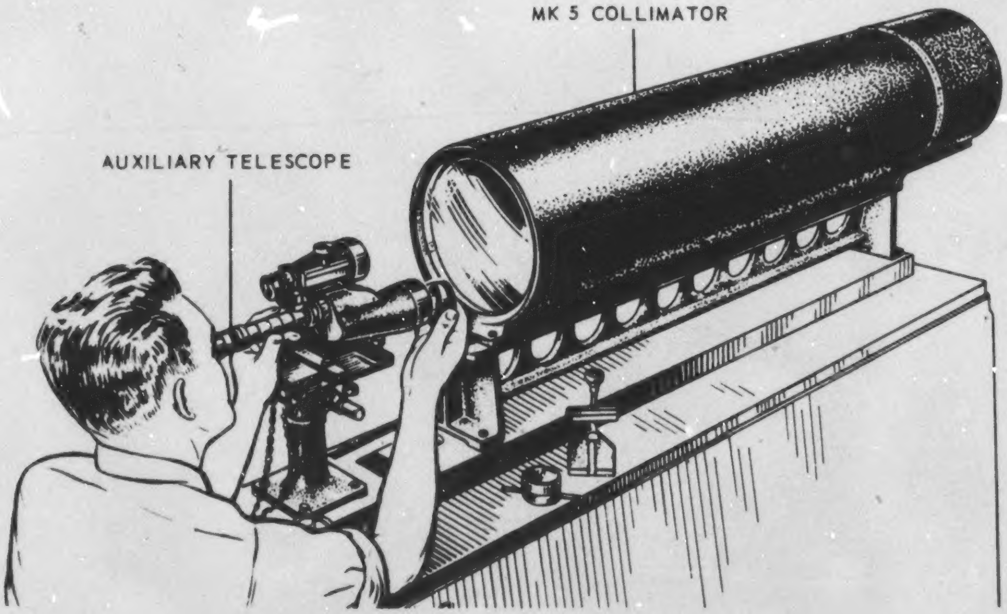
The assembled binocular (except for objective seals, lockrings, and objective caps) is mounted on a Mk 5 collimator, as shown in figure 10-64. Notice that the binocular is mounted upside down, and the right hinge lug is clamped in the fixture so the left body is free to move.

Using an auxiliary telescope with rhomboid attachment, focus both eyepieces on the collimator target and set the focusing rings to zero diopters (within ±1/4 diopter of each other). At this time, the eyepieces should be of equal height within 1/16 inch. (Check with a straightedge.) Also check for lean by comparing the magnified collimator target, seen through the eyepieces, with the smaller collimator target picked up by the rhomboid attachment. Correct any problems noted before proceeding.

To align both lines of sight with the hinge axis, use the tail-of-arc method, explained next.

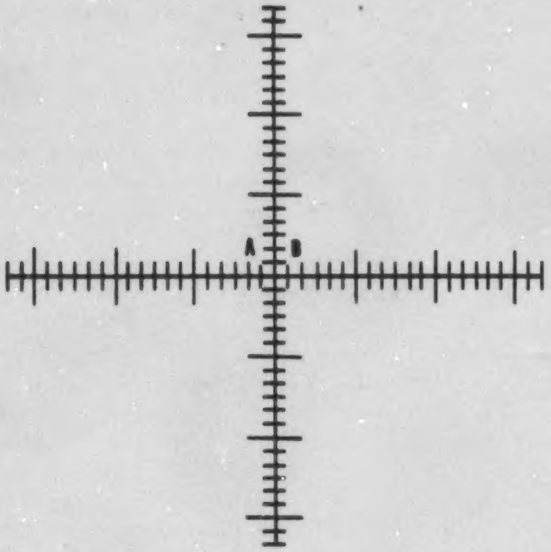
1. Swing the left body all the way up to show approximately 58 mm on the IPD scale. Using the auxiliary telescope, adjust the screws on the collimator fixture to align the normal and magnified target image. See figure 10-65.

2. Now swing the left body down to obtain the widest separation between eyepieces (74 mm). What you see through the auxiliary telescope should be similar to figure 10-66. The smaller target (A) is a stationary reference

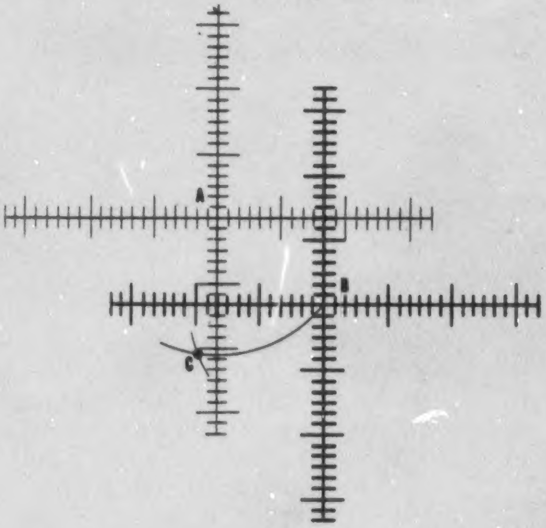


137.489

Figure 10-64.—Mark 5 binocular collimator.



137.490
Figure 10-65.–Collimator crosslines superimposed at 58 mm interpupillary distance.



137.492
Figure 10-66.–Preliminary step in binocular tail-of-arc collimation.

picked up by the rhomboid. The magnified target (B), seen through the left barrel, shows how far the line of sight deviates from parallelism with the hinge. NOTE: To make collimation easier, the objective eccentric rings should be set for minimum displacement when assembled.

3. To adjust the line of sight, first, construct an imaginary equilateral triangle shown by points A, B, and C in figure 10-66. Point C must always be figured in a clockwise direction from point B, regardless of where the magnified crossline ends up after swinging the left body. NOTE: The small crossline may appear to move.

4. With the left telescope still at 74 mm IPD, manipulate the objective eccentrics to place the magnified target image (B) in the area of imaginary point (C). Try to make this adjustment without disturbing the binocular on the collimator fixture. NOTE: First, rotate the entire objective assembly (inner and outer eccentric). If this does not move the magnified target to point C, throw some eccentricity into the objective and rotate the complete assembly again.

5. After you are satisfied that the crossline is near point C, swing the left body back to 54 mm IPD and adjust the collimator fixture to superimpose the two crosslines (fig. 10-65). Repeat steps 2 through 5 until there is no displacement of the magnified crossline when you swing the left barrel from 54 mm to 74 mm.

If you find there is not enough eccentricity in the left objective to satisfy collimation requirements, you will have to shift prisms. After shifting prisms, check zero diopters, equal eyepiece height, and lean again before recollimating.

6. Once the left body is collimated, swing that body down to approximately 64 mm, realign the two crosslines by adjusting the collimator fixture, and adjust the right objective to superimpose the two crosslines seen through the auxiliary telescope. Recheck the left and right bodies to be sure you have perfectly superimposed the crosslines. NOTE: If you

cannot superimpose the line of sight with the right objective eccentrics, shift prisms and proceed as indicated in step 5 above.

7. Tighten the eccentric lock screws, replace gaskets and rings, replace and lock the objective lockring, and replace the objective caps. NOTE: Tightening the eccentric lock screws and the objective lock rings may throw collimation off. Recheck and adjust as necessary.

Collimation tolerance for both lines of sight in a binocular are specified as (a) 2′ step (vertical displacement), (b) 4′ divergence (outward separation), and (c) 2′ convergence. These tolerances represent government performance standards for binoculars. You will not find an optical shop supervisor who will accept these sloppy tolerances. If your collimation is not perfect, it is not good enough.

Complete overhaul information for Navy hand held binoculars is found in NAVSHIPS 250-624-2.

At this point we must warn you about differences in imported binoculars. U.S. military binoculars are the best in the world, and they cost about $350 each. If you pay $35 to $120 for an import, the cost is comparable to quality. Optically, imported prismatic binoculars are excellent, but collimation is difficult due to loose tolerances, no eccentrics on some models, and sloppy prism mounting. In fact, prisms are glued in some cheaper models. Power is also excessive, sometimes as high as 20X in a hand held instrument.

Another cheap shortcut found in many imports is the use of a center focusing arrangement, rather than individual focusing eyepieces. In this system, a large focus knob mounted on top of the hinge drives a multiple lead shaft up or down inside the hinge. Attached to the top of the shaft by another hinge are the two eyepieces which slide up or down on tubes screwed into the top cover plates. To account for differences in diopter setting between the left and right eye, the right eyepiece is focused in the normal manner.

The major shortcoming of center focus binoculars is that close fitting of sliding components is not possible if the focusing mechanism is going to work at all. The loose fitting eyepieces, combined with high magnification and sloppy prism mounting, will be the ultimate test of your skill and patience if you ever attempt to repair such binoculars.

SHIP MOUNTED BINOCULAR

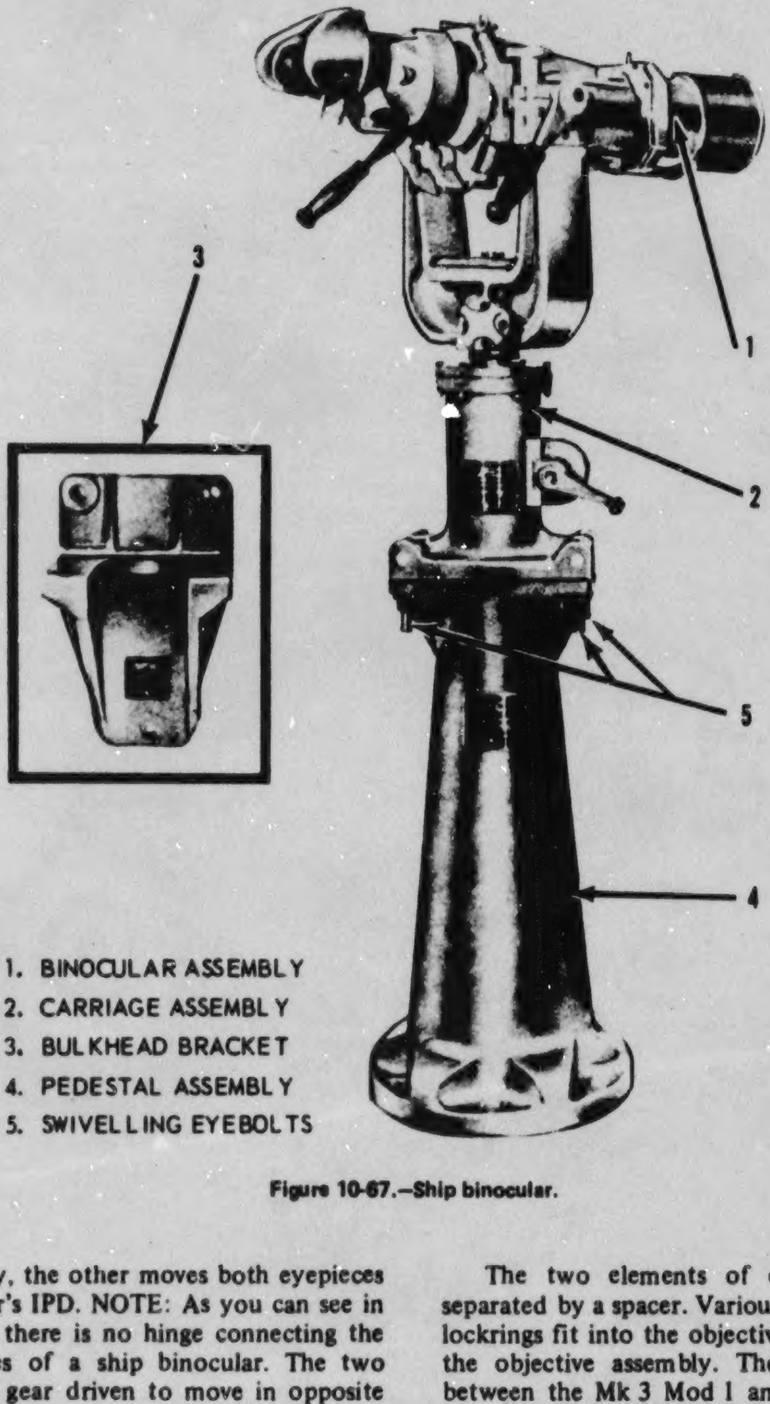
A completed ship binocular is shown in figure 10-67. The optical arrangement is similar to hand held binoculars except that polaroid filters and clear compensators are provided, and the ship binocular uses an internal focusing eyepiece. Characteristics of the ship binocular follow:

Magnification	20 power
Clear aperture of objective	120 mm
True field of view	3°30′
Eye distance at zero diopters	22.5 mm
Apparent field (approx.)	70°
Exit pupil	6 mm
Interpupillary distance	56-74 mm
Overall binocular length (sunshade extended)	20.375 inches
Overall binocular width	22.5 inches

Construction Features

The Navy uses three similar types of ship binoculars, the Mk 3 Mod 1, Mk 3 Mod 2, and the Mk 3 Mod 4. An exploded view of the Mk 3 Mod 4 is shown in figure 10-68. This instrument may look like a nightmare, but it really isn't very complicated.

Most ship binoculars are sealed with O-rings, packing, and sealing compound to maintain an internal pressure of 2 psi. Two shafts extend through the eyepiece housing. One controls the



1. BINOCULAR ASSEMBLY
2. CARRIAGE ASSEMBLY
3. BULKHEAD BRACKET
4. PEDESTAL ASSEMBLY
5. SWIVELLING EYEBOLTS

69.18

Figure 10-67.–Ship binocular.

filter assembly, the other moves both eyepieces to set the user's IPD. NOTE: As you can see in figure 10-68, there is no hinge connecting the two telescopes of a ship binocular. The two eyepieces are gear driven to move in opposite directions.

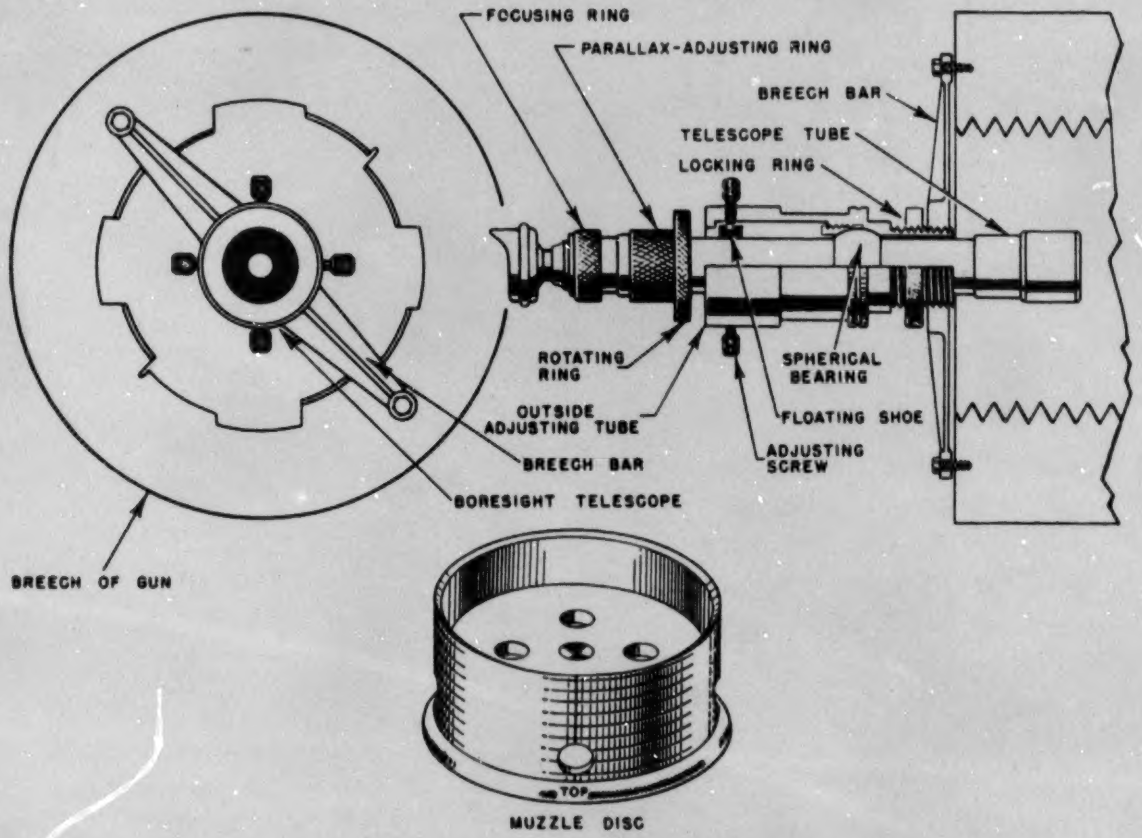
The two elements of each objective are separated by a spacer. Various spacers, seals, and lockrings fit into the objective tube to complete the objective assembly. The major difference between the Mk 3 Mod 1 and Mk 3 Mods 2, 3, and 4 is the means for adjusting the objectives during collimation. In the Mk 3 Mod 4 (illustrated) eccentric buttons (30) are used to shift the objective assembly. The Mk 3 Mod 1 uses eccentric rings. Complete information on overhaul, adjustment collimation, sealing, and drying is found in NAVSHIPS 324-0516 and NAVSEA S9421-AA-MMA-010.

BORESIGHT TELESCOPES

As the name implies, a boresight is used to accurately align the point of aim of a naval gun with associated sighting equipment and mechanisms. A typical setup is shown in figure 10-69. The boresight is mounted on a breech bar, which centers it in the breech, and a close fitted muzzle disc, with centered peep hole, is slipped in the muzzle. The boresight can be adjusted to center a crossline on the muzzle disc, then the boresight can be focused on a selected external target so associated equipment can be aligned to the gun bore on the same target.

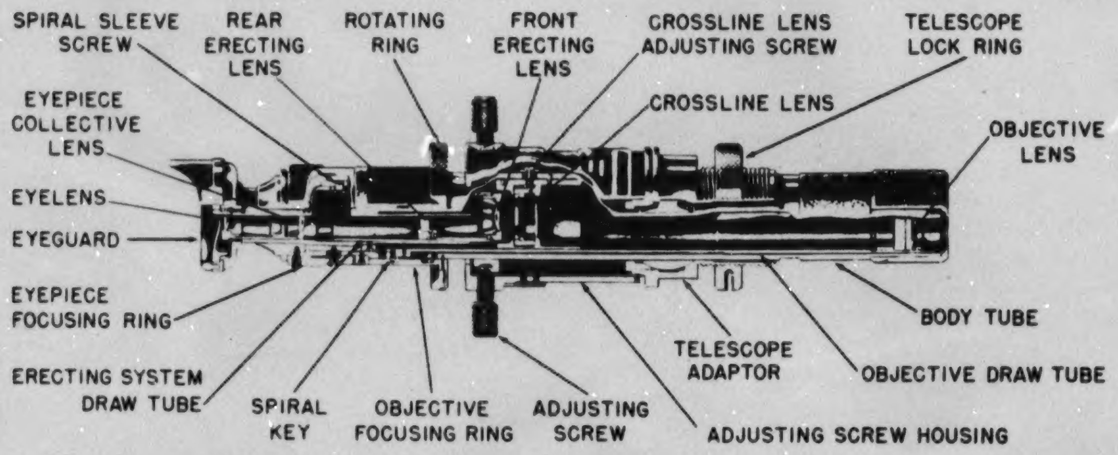
CONSTRUCTION FEATURES

Two similar instruments are shown in cutaway form in figures 10-70 and 10-71. Even though there are some optical and mechanical differences, the boresights are interchangeable in function.

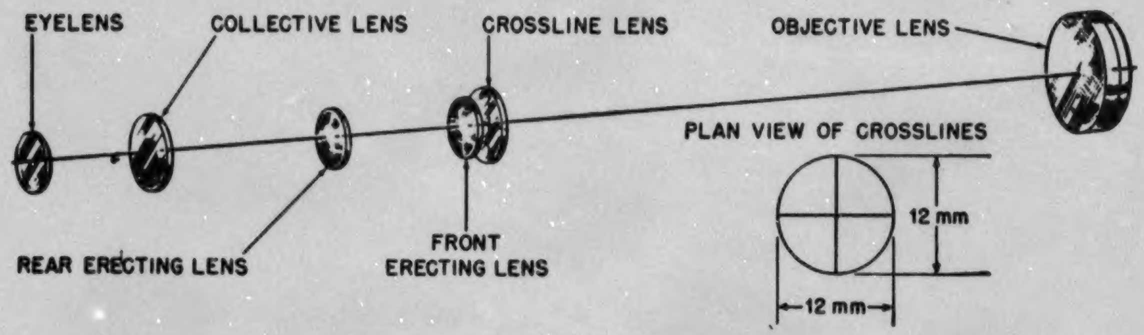


110.80

Figure 10-69.—Typical boresighting equipment.



A. CUTAWAY VIEW



B. LENS SYSTEM

137.270(271)

Figure 10-70.–Optical and mechanical system of a Mk 8 Mod 6 boresight.

Optical characteristics of the two boresights are listed below:

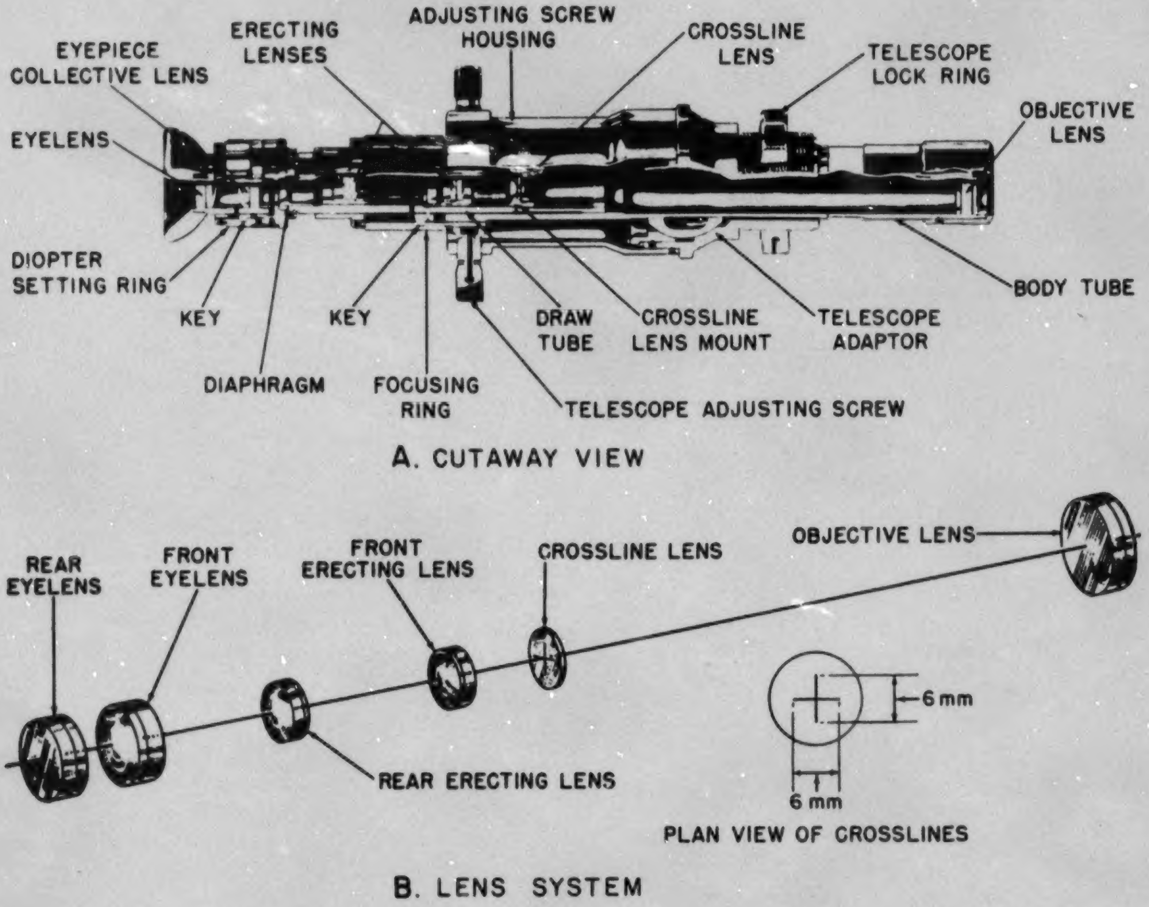
Mk 8 Mod 6

Magnification	9.6X
Field	2° 30′
Exit pupil	2.3 mm
Eye distance	11.0 mm

Mk 75 Mod 1

Magnification	8X
Field	3° 20′
Exit pupil	2.5 mm
Eye distance	19.4 mm

Notice that these boresights have a small field angle and a tiny exit pupil. Considering that they are used only for infrequent alignment purposes, these features are not objectionable.



84.207(137.257)

Figure 10-71.—Optical and mechanical system of a Mk 75 Mod 1 boresight.

Another necessary characteristic for a boresight is the ability to focus on objects at various distances. The Mk 8 Mod 6 can focus on objects from 6 feet to infinity. This is accomplished by mounting the objective lens in a draw tube so it can be moved in relation to a fixed crossline to provide a parallax-free view of the target. The eyepiece system of the Mk 8 Mod 6 is also in a fixed position. Focusing is provided by mounting the erecting system in a draw tube.

The Mk 75 Mod 1 boresight is capable of focusing on objects between 10 feet and infinity. In this telescope, the objective is fixed and the crossline and erectors are mounted in a drawtube. It is also a focusing eyepiece.

As you can see in figures 10-70 and 10-71 both telescopes have a spherical bearing on the body tube which fits a socket in the telescope adapter. When the telescope adapter is screwed into a fixture and secured with the telescope lockring, the four telescope adjusting screws can be manipulated to accurately position the line of sight.

Notice in figure 10-72 the Mk 8 Mod 6 boresight has a rotating ring and crossline adjusting screws. This feature allows you to remove eccentricity between the target and crossline. The Mk 75 Mod 1 does not have this feature because the crossline lens is accurately ground to be perfectly concentric with the crossline and the mounts and body tubes.

REPAIR AND ADJUSTMENT

Boresight telescopes are sturdy but delicate. They are stored in a protective box most of the time. However, accidents do happen. Usually, they are sent to the optical shop only for cleaning and lubrication.

In a boresight, screws are small, threads are very fine, the lenses are small, and mating parts are closely fitted. You must be very careful when disassembly is necessary to avoid damaging or deforming any parts. It would be advisable to make some special tools for removing lockrings.

The complete description and overhaul procedures for the Mk 8 Mod 6 and Mk 75 Mod 1 boresights is contained in OP 1449.

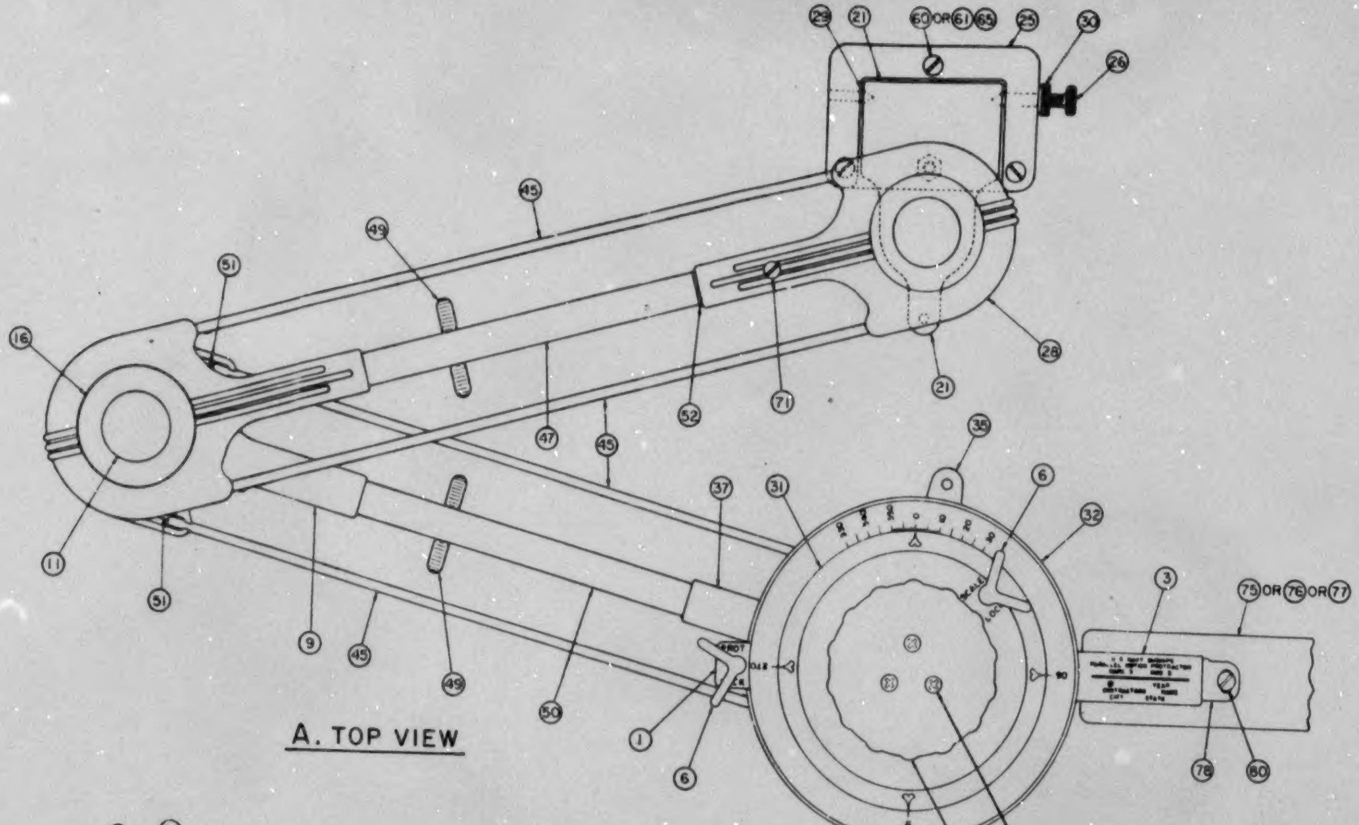
C. PARTS LIST

PC NO.	NAME	BUSHIPS DWG NO.
1.	PROTRACTOR LOCK	S2407/533729
2.	PROTRACTOR LOCK PLATE	" "
3.	BASE PLATE	" "
4.	SPINDLE UNIT	" "
5.	SKID BUTTON	" "
6.	"L" NUT	" "
7.	SCALE LOCK SCREW	" "
8.	"L" NUT SPRING	" "
9.	ELBOW BRACKET	" "
10.	ELBOW PULLEY	" "
11.	BRAKE KNOB	" "
12.	BRAKE KNOB INSERT	S2407/533730
13.	LOWER BRAKE SHAFT	" "
14.	LOWER BRAKE PLATE	" "
15.	BRAKE LINING	" "
16.	UPPER BRAKE	" "
17.	ELBOW SPINDLE	" "
18.	BRAKE DISC	" "
19.	ELBOW NUT	" "
20.	BRACKET SUPPORT	" "
21.	HINGE MOUNTING	" "
22.	PIN	" "
23.	SET SCREW (COMM. HEADLESS)	¼" - 28 X $\frac{5}{8}$" LONG
24.	JAM NUT	¼" - 28
25.	ANCHOR PLATE	S2407/533732
26.	ANCHOR SCREW	S2407/533731
27.	MAST PULLEY	" "
28.	FORK BRACKET	" "
29.	ANCHOR PIVOT	" "
30.	LOCK NUT	" "
31.	WITNESS PLATE	" "
32.	PROTRACTOR	" "
33.	HEAD PULLEY	" "
34.	SPINDLE BUSHING	S2407/533732
35.	BRACKET PLATE	" "
36.	SPINDLE PIN	" "
37.	HEAD BRACKET	" "
38.	HANDLE	" "
39.	LOCK NUT	" "
40.	"L" NUT SHIM	" "
41.	SPINDLE BUSHING SHIM	" "
42.	HINGE MOUNTING MAST SCREW	" "
43.	FRICTION PLATE	" "
44.	MAST	" "
45.	BAND COVER	" "
46.	BRAKE SCREW	" "
47.	UPPER TUBE	S2407/533733
48.	TUBE BUSHING	" "
49.	TUBE TIGHTENING PIN	" "
50.	LOWER TUBE	" "
51.	BAND	" "
52.	THRUST WASHER	" "
53.	HINGE MOUNTING WRENCH	" "
54.	CHUCK WRENCH	" "
55.	CHUCK WRENCH PIN	" "
56.	THRUST PLUG	" "
57.	THRUST SCREW	" "
58.	SUPPORT-STEEL TUBE	" "
59.	MACH. SCREW (OVAL PHILLIPS)	8 - 32 X 1¼" LONG
60.	WOOD SCREW (OVAL HD.)	10 X 1½" LONG
61.	MACH. SCREW (OVAL HD.)	10 - 32 X 2" LONG
62.	RIVET	$\frac{3}{32}$" X $\frac{5}{16}$" RD. HD.
63.	HEX NUT	¼" - 28
64.	MACHINE SCREW (FILLISTER HD.)	2 - 56 X $\frac{3}{16}$" LONG
65.	HEX NUT	10 - 32
66.	ALLEN WRENCH (NO. 18)	S2407/533733
67.	BEARING	FAFNIR T-202-C2-KDD-$\frac{15}{MM}$
68.	MACH. SCREW (RD. HD.)	8-32 X 1" LONG
69.	LOCK PLATE SCREW	S2407/533733
70.	BEARING	FAFNIR T-201-C2-KDD-$\frac{15}{MM}$
71.	MACH. SCREW (OVAL HD.)	8-32 X ½" LONG
72.	"L" NUT BUSHING	S2407/533733
73.	RIVET	" "
74.	MACH. SCREW (RD. HD.)	8-32 X ½" LONG
75.	SCALE (32ND & 50TH)	S2407/533734
76.	SCALE (16TH & 20TH)	" "
77.	SCALE (32ND & 40TH)	" "
78.	SCALE CHUCK	" "
79.	SCALE CHUCK SCREW	" "
80.	SCALE SCREW	" "
81.	SCALE CHUCK BUSHING	" "
82.	NAMEPLATE (CARRYING CASE)	
83.	PIN (ESCUTCHEON)	18 X $\frac{3}{8}$" LONG
84.	CARRYING CASE	S2407/533734

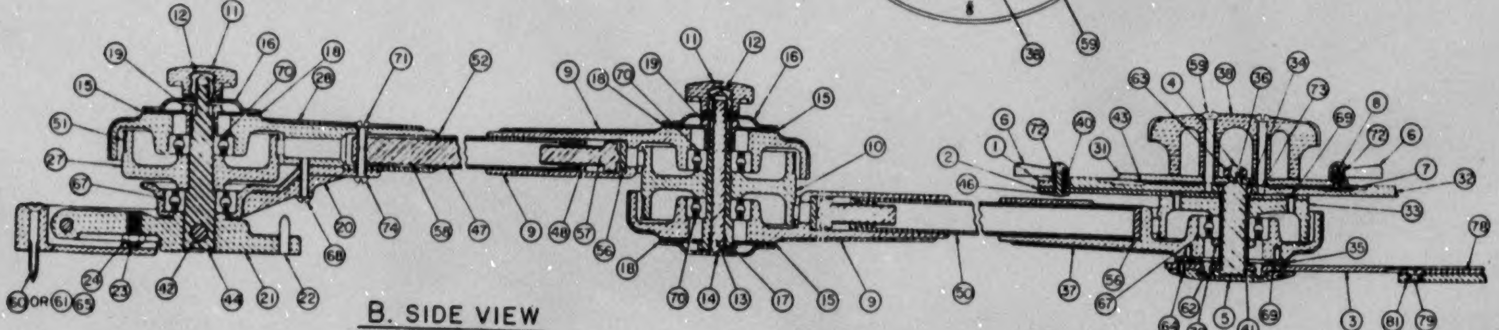
DRAFTING MACHINE
(PARALLEL MOTION PROTRACTOR TYPE)
MARK 3 MOD. 3
GENERAL ASSEMBLY
S2407H/533728

137.568

Figure 10-2.—Parallel motion protractor parts identification.

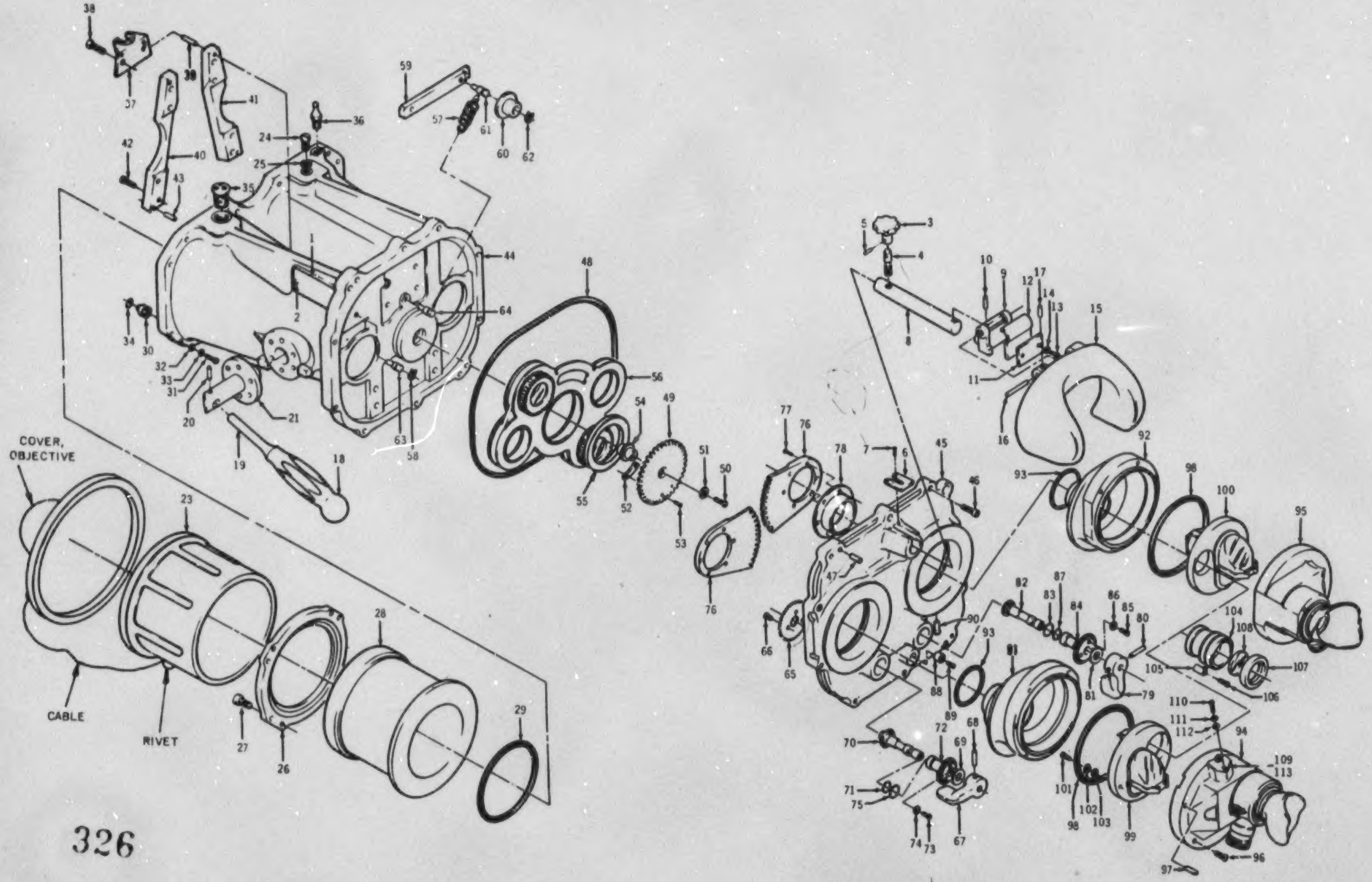


A. TOP VIEW



B. SIDE VIEW

1. PLATE, IDENTIFICATION (ATTACHING PARTS)
2. SCREW
3. KNOB, HEADREST
4. PIN
5. PIN
6. PLATE, RETAINING
7. SCREW
8. SHAFT
9. HINGE, HEADREST
10. PIN
11. PLATE, CLAMP
12. STRAP, RETAINING
13. SCREW
14. WASHER
15. HEADREST
16. PIN, HINGE
17. PIN
18. GRIP
19. HANDLE
20. PIN
21. SHAFT, PIVOT
22. SCREW
23. VISOR, BINOCULAR
24. SCREW
25. WASHER
26. CLAMP, OBJECTIVE
27. SCREW
28. CELL, OBJECTIVE
29. SEAL
30. SHAFT, ECCENTRIC
31. SCREW
32. WASHER
33. WASHER
34. PACKING
35. VALVE, GAS
36. SIGHT, FRONT
37. BRACKET, CARRIAGE
38. SCREW
39. PIN
40. DOVETAIL LH
41. DOVETAIL RH
42. SCREW
43. PIN
44. HOUSING, MAIN
45. HOUSING, FILTER
46. SCREW
47. PIN
48. SEAL
49. GEAR, IDLER, FILTER
50. SCREW
51. WASHER
52. PLATE, ACTUATOR
53. SCREW
54. SHAFT, IDLER GEAR
55. RING, RETAINING
56. FILTER ASSEMBLY
57. SPRING, DETENT ARM
58. RING, RETAINING
59. ARM, DETENT
60. ROLLER, DETENT
61. PIN, DETENT ARM
62. RING, RETAINING
63. PIN, PIVOT
64. GROOV-PIN
65. GEAR, FILTER ADJUST
66. SCREW
67. KNOB, FILTER
68. PIN, SPRING
69. SHIM, WASHER
70. SHAFT, ADJUSTING
71. PACKING
72. BEARING, SLEEVE
73. SCREW
74. WASHER
75. PACKING
76. GEAR, SECTOR
77. SCREW
78. BEARING, SLEEVE
79. KNOB, INTEROCULAR ADJUST
80. PIN, SPRING
81. SHIM, WASHER
82. GEARSHAFT, INTEROCULAR
83. PACKING
84. BEARING, SLEEVE
85. SCREW
86. WASHER
87. PACKING
88. SPACER, STOP
89. SCREW, FIL HD, SLOT
90. BUTTON, STOP
91. HOUSING, PRISM LH
92. HOUSING, PRISM RH
93. SEAL
94. HOUSING, EYEPIECE LH
95. HOUSING, EYEPIECE RH
96. SCREW,
97. PIN
98. PACKING
99. PRISM ASSEMBLY LH
100. PRISM ASSEMBLY RH
101. SCREW
102. WASHER
103. WASHER
104. SPACER, SLEEVE, RETICLE
105. CLAMP, RIM
106. SCREW
107. HOUSING, RETICLE
108. WINDOW, COMPENSATOR
109. PLUG, ACCESS
110. SCREW
111. WASHER
112. WASHER
113. PACKING
114. KNOB, DIOPTER ADJUST
115. SET SCREW
116. PIN
117. PACKING
118. BEARING, SLEEVE
119. SCREW
120. PACKING
121. SHAFT, DIOPTER ADJUST
122. CAM, CONTROL, DIOPTER
123. PACKING
124. SHIM, WASHER
125. CLAMP, LOOP, EYEGUARD
126. EYEGUARD
127. HOUSING, EYELENS
128. SCREW
129. PACKING
130. RING, RETAINING, EYELENS
131. LENS, EYEPIECE
132. HOUSING, LENS, EYEPIECE
133. RING, RETAINING
134. LENS, TRIPLET, EYEPIECE
135. LENS, DOUBLET, EYEPIECE
136. SPACER, LENS, EYEPIECE



148.110

Figure 10-68.—Ship binocular assembly Mk 3 Mod 2.

CHAPTER 11

NIGHT VISION SIGHTS AND GUNSIGHTS

You might think it strange to combine two seemingly different types of instruments in one chapter, but there are some similarities to justify this action. In the first place, several of the night vision sights being discussed are actually used as gunsights. Secondly, both categories of instruments combine conventional optics with some electrical or electronic application.

This chapter, therefore, is an introduction to electro-optical instruments.

NIGHT VISION SIGHTS

Thus far, you have been exposed to optical instruments that function in bright light or rely on a luminous or illuminated target to form a useful image. Night vision sights are electro-optical devices which are designed for use when there is not enough light for a conventional telescope to form an image.

We will discuss three passive instruments which emit no light during operation; consequently, they cannot be detected. These devices electronically amplify available light 35,000 to 50,000 times so the operator can clearly distinguish objects. We will also describe an infrared telescope, considered an active instrument since it generates a beam of infrared to illuminate targets. Infrared is not visible to the unaided eye, but the enemy, using infrared-sensitive instruments, can detect our operators.

COMPONENTS

A night vision sight (NVS) consists of three optical assemblies: the objective elements, the image intensifier tube (IIT), and the eyepiece system. The objective assembly, consisting of multiple lenses (or mirrors), focuses available light on the first stage of a three-stage IIT. The IIT amplifies the light through a process of electron emissions from phosphor screens, then presents this light to a focusing eyepiece for final magnification. A very basic schematic of a typical NVS system is shown in figure 11-1.

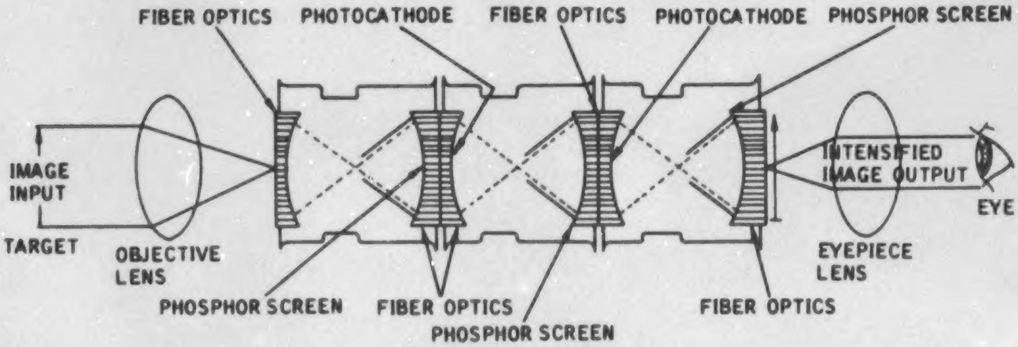
Two types of IIT are in current usage, and they can be used in all three night vision sights being discussed. The older type IIT could not tolerate bright light without overloading. Too much exposure would burn out the unit. A new automatic brightness control (ABC) IIT can accept higher light levels and will also turn itself off to prevent damage.

MK 36 NVS

The Mk 36 NVS (fig. 11-2) is a lightweight (6 pounds) 4-power instrument which can be hand held or mounted on various light rifles or machineguns. It has an objective assembly which can be focused on objects from 4 yards to infinity.

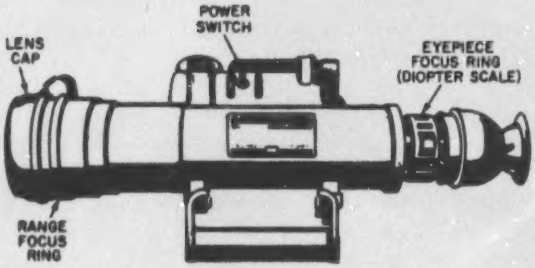
MK 37 NVS

The Mk 37 NVS (fig. 11-3) is a bridge-mounted sight with a power of 5.5 or 7.5, depending on the eyepiece used. The objective assembly can focus on objects from 50 yards to infinity.



137.559

Figure 11-1.—Image intensifier diagram.



137.546A

Figure 11-2.—Night vision sight Mk 38.

CREW SERVED WEAPON SIGHT (CSWS)

The CSWS (fig. 11-4) is a 7-power instrument with two types of illuminated reticles. This NVS is mounted on heavy machineguns, recoilless rifles, or 20-mm cannon. Objective focus range is the same as the Mk 37. The boresight mount assembly shown is also used on the Mk 36 NVS.

A representative power supply assembly is shown in figure 11-5. A mercury battery (6.8 VDC) powers an oscillator which converts the low d.c. voltage to 2800 VAC. This higher a.c. voltage is further boosted by the IIT to approximately 45,000 V during the process of light amplification. The Mk 36 and Mk 37 are also supplied with a converter so 115-VAC power can be used in place of the battery.

METASCOPE

The infrared telescope (metascope) is shown in figure 11-6. The receiver portion, which detects other infrared sources, is a 1.1X telescope, with focusing eyepiece and objective (adjustable for targets from 12 inches to infinity). A mercury battery (1.34 VDC) activates a power supply which steps the voltage up to 11,500 VDC. The power supply output energizes a single-stage image tube which functions similarly to the IIT in a NVS. The light source of the metascope is nothing more than a two-cell flashlight with an infrared filter over the reflector. With the light source attached to the receiver, and activated, the target is bathed in invisible infrared light which is converted to a visible image by the image tube in the receiver.

REPAIR AND ADJUSTMENT

The primary safety consideration in working with an NVS is the high voltage in the IIT assembly. This voltage must be discharged, as specified in OP 4067, BEFORE you attempt any internal repairs. It is also important to avoid damaging the IIT. The coating on the phosphor screen is toxic. You must not inhale it nor allow it to come in contact with your mouth or any open wounds.

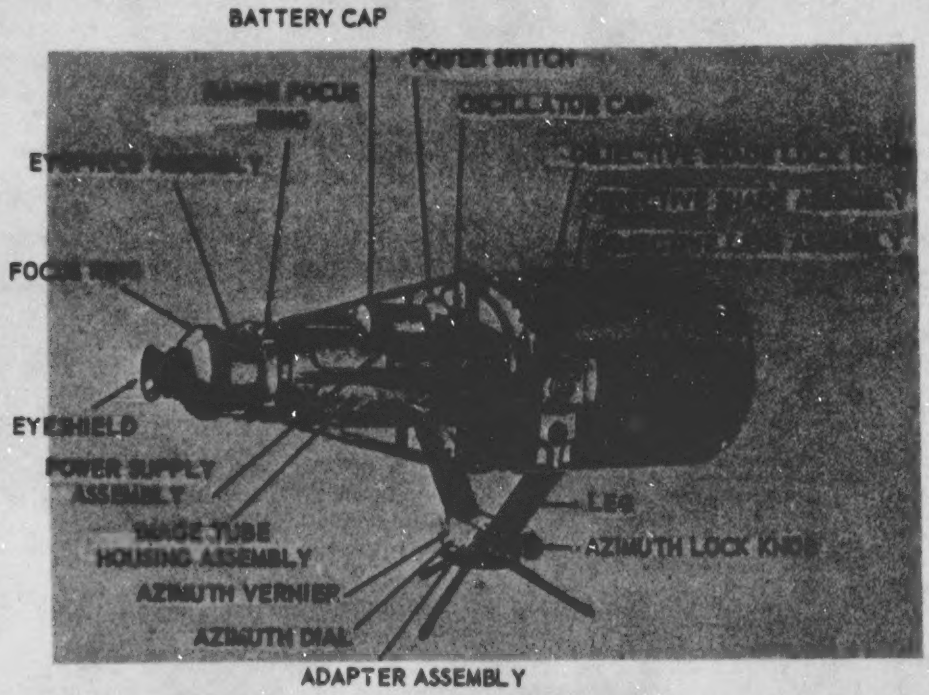
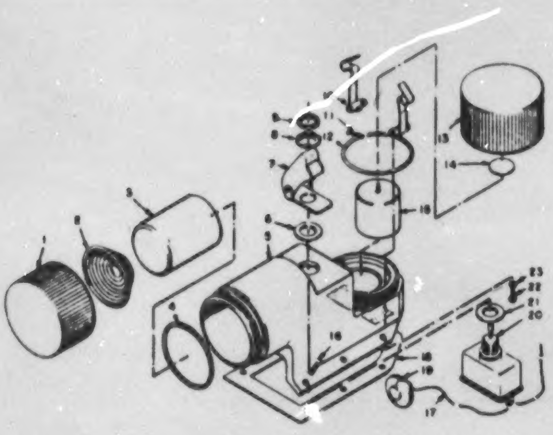


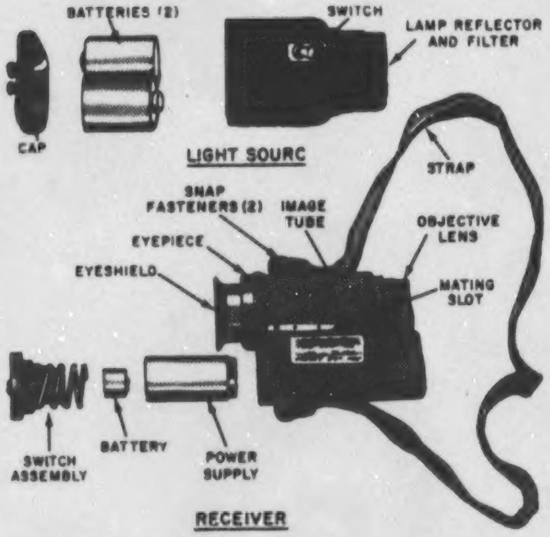
Figure 11-3.—Night vision sight Mk 37. 137.544

Figure 11-4.—Crew served weapon sight. 137.543



137.551

Figure 11-5.—Power supply assembly, exploded view.



137.560

Figure 11-6.—Metascope components.

Repairs to night vision sights are limited to continuity checks of switches and wiring, replacement of defective electrical components, cleaning external optics, replacing various seals, and replacement (turn-in) of damaged or unserviceable optical components. Further repair or disassembly is not normally authorized.

Limited repair procedures for night vision sights are contained in OP 4067. A description of detailed overhaul of night vision sights can be found in chapter 5 of *Opticalman 1 & C*, NAVTRA 10206-series.

GUNSIGHT TELESCOPES

Gunsight telescopes vary from small, fixed line of sight instruments to large servocontrolled tilting prism sights. The small sights are mounted on open gun mounts, larger sights are found in closed twin mounts, and the modern instruments are mounted on gunfire directors or in gun mounts.

Older gunsights were designed so one person could sight the target and control elevation while another person, using a similar sight, would train the gun. Range to a target was determined by rangefinder or radar, and the pointer and trainer would observe the effect of gunfire and adjust train and elevation accordingly.

Large guns, in closed mounts, used several different types of sights which were mechanically connected to the elevation/train mechanism. With this arrangement, the operators could observe the effects of gunfire without changing position. Aiming of the guns and sights was normally controlled from the director, but local control could be used if necessary.

This section will deal with only one type of older gunsight. If additional information is needed, refer to OP 582.

MK 67 AND MK 68 GUNSIGHTS

The Mk 67 gunsight (fig. 11-7) is a 6X, tilting prism gunsight about 4 feet long and weighing approximately 180 pounds. The Mk 68 telescope is essentially a mirror image of the Mk 67. The optical system is shown in figure 11-8.

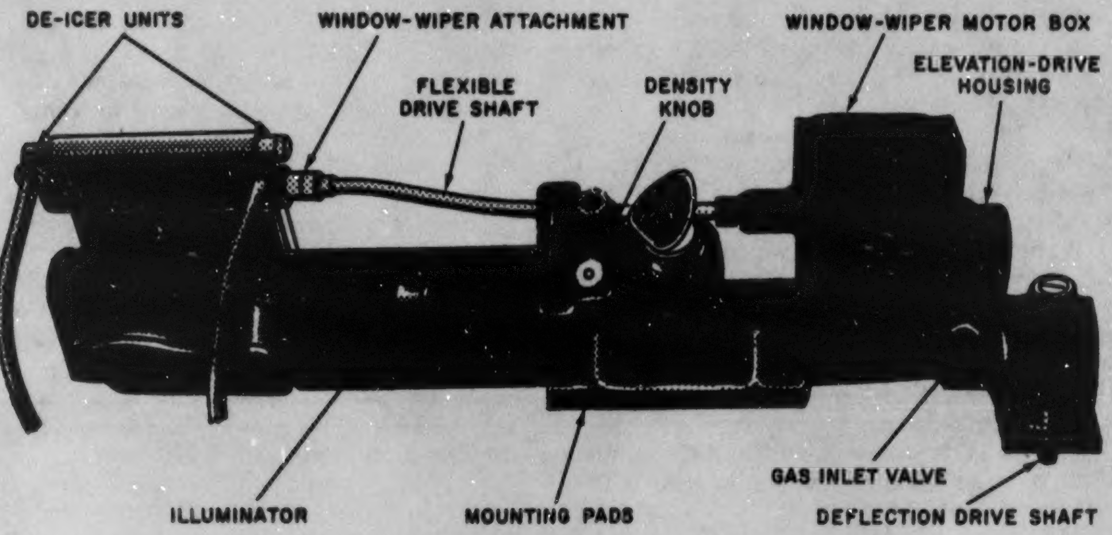


Figure 11-7.—Telescope Mk 67. 137.561

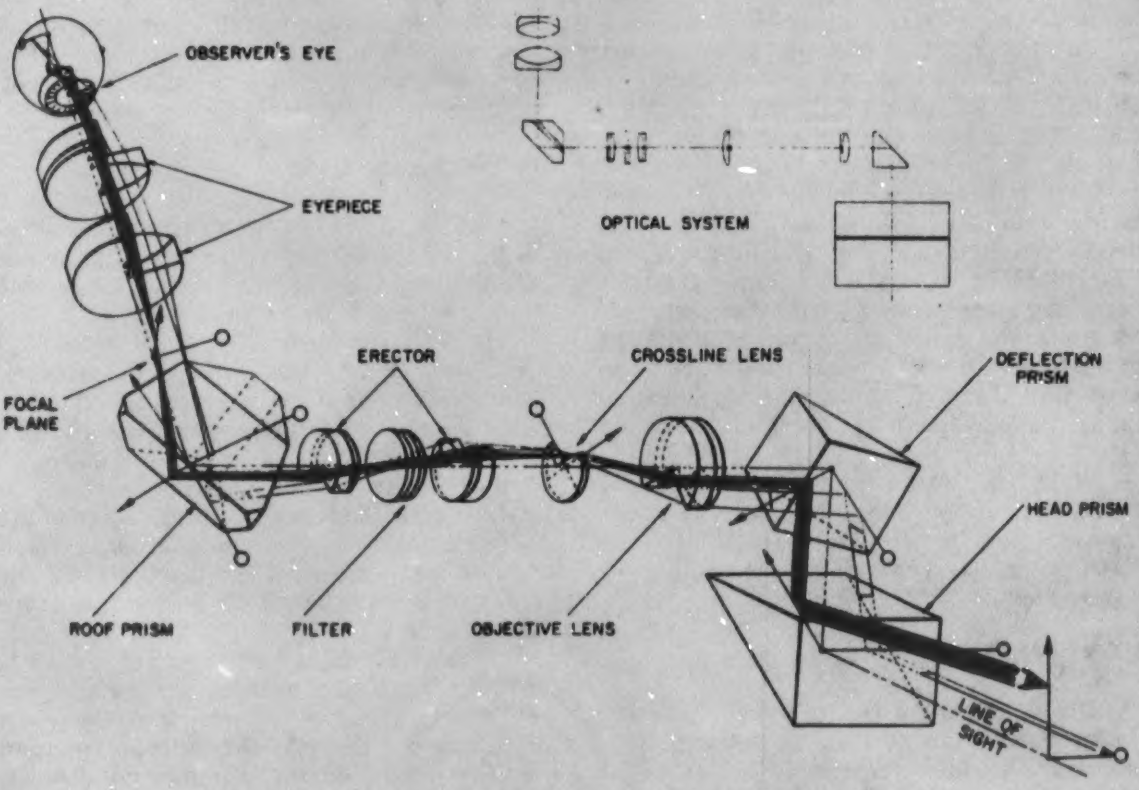


Figure 11-8.—Optical system, telescope Mk 67. 145.138

Three of these instruments are found in a 5 inch-38 twin mount, one each for the pointer and checker (Mk 67), and one for the trainer (Mk 68).

The line of sight, controlled by suitable shafts and gears, is movable from +85° to -15° in elevation, with maximum deflection of 20° left or right.

Various cover plates and windows, sealed by flat gaskets, allow access to the optical and mechanical components for disassembly and adjustment. It is very important that you use scribe lines and punch marks (bench marks) during disassembly and reassembly of the Mk 67 and Mk 68 telescopes.

The crossline and rear erector are mounted in an inner optical tube which is secured in the outer optical tube. The objective lens is threaded into the outer end of the outer optical tube. The rear erector is secured in a mount threaded into the body casting. Notice that the filter assembly is located between the erecting lenses; consequently, no clear compensator is necessary.

Collimation of a gunsight must be very accurate for obvious reasons. Accuracy is possible only if you properly adjust the Mk 9 collimator and follow the collimation steps outlined in OP 582 in sequence.

There is no tolerance for parallax. Deflection backlash must be held to 30″ and elevation backlash must be no more than 1′. The line of sight, in full left or right deflection, must be in a horizontal plane within 2′ (vertical separation of the horizontal crosslines). Elevation of the line of sight can vary from a true vertical plane by no more than 2′ at 90° (horizontal separation of the vertical crosslines).

NOTE: Horizontal or vertical displacement is determined by comparing the telescope crossline with the collimator crossline. Any variation from perfect superimposition is displacement.

MK 97 TELESCOPE

The Mk 97 is the first of a line of roughly similar director-mounted sights. Although it is much smaller than the Mk 67 or Mk 68, it weighs 190 pounds. The Mk 97 is an 8X terrestrial binocular with a front surface aluminized mirror which provides elevation of the line of sight from -25° to +95°. A reticle, consisting of two concentric circles, is located in the right eyepiece system (internal-focusing).

The optical system (fig. 11-9) is somewhat unusual, especially the shape of the roof prisms, but easy to understand. You can rotate the left rhomboid prism and eyepiece assembly for interpupillary adjustment.

Figure 11-10 shows an exploded view of major components of the Mk 97 telescope. The mirror tilt drive assembly is very precise for such a bulky looking instrument; one degree of input shaft rotation must move the mirror.

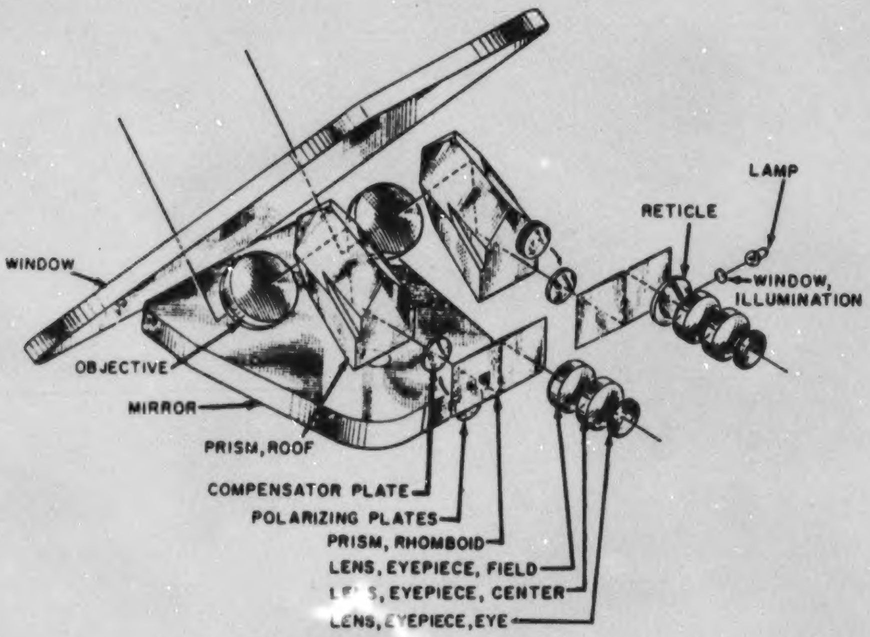
Reference surfaces for collimation of the Mk 97 consist of the bottom surfaces of the mounting feet and the left vertical edges of the left mounting feet. Once you have mounted the collimator fixture on the Mk 9 collimator and adjusted the collimator, all other adjustments you make are made to these surfaces. Needless to say, you must handle the instruments carefully to avoid marring the mounting feet.

Collimation of Mk 97

Collimation of the Mk 97 telescope consists of leveling the mirror, setting zero diopters, and adjusting the objective eccentrics to align both lines of sight with the collimator.

To level the mirror, install the mirror tilt drive assembly and the mirror in the telescope body. Then clean the mounting feet and set the telescope on a large surface plate. Use a surface gage and sensitive dial indicator (.0001-inch graduations) to establish parallelism between the surface plate and mirror. NOTE: Since this mirror is front-surface aluminized, use extreme caution when cleaning and leveling. The dial indicator should contact the mirror only at the extreme edges.

Operate the mirror tilt drive input shaft to establish parallelism between the surface plate and front-rear mirror surfaces. If you note any error between the left-right surfaces, you must carefully scrape the mirror mount to eliminate the error. The tolerance for mirror parallelism is 0.00075 inch.



148.308

Figure 11-9.—Mk 97 optical system.

Use standard techniques to set zero diopters and equal focusing of both eyepieces. Use a stereo comparator when adjusting the objectives to align both lines of sight with the collimator.

Complete procedures for overhaul, collimation, and sealing/drying of the Mk 97 telescope are found in OP 1857.

MK 100 TELESCOPE

The Mk 100 telescope is similar to the Mk 97, except that it has a change of magnification feature (6X and 10X). In the 10X position, shown in figure 11-11, the auxiliary lenses are out of the line of sight. When the auxiliary lenses are in the line path, overall magnification is reduced to 6X.

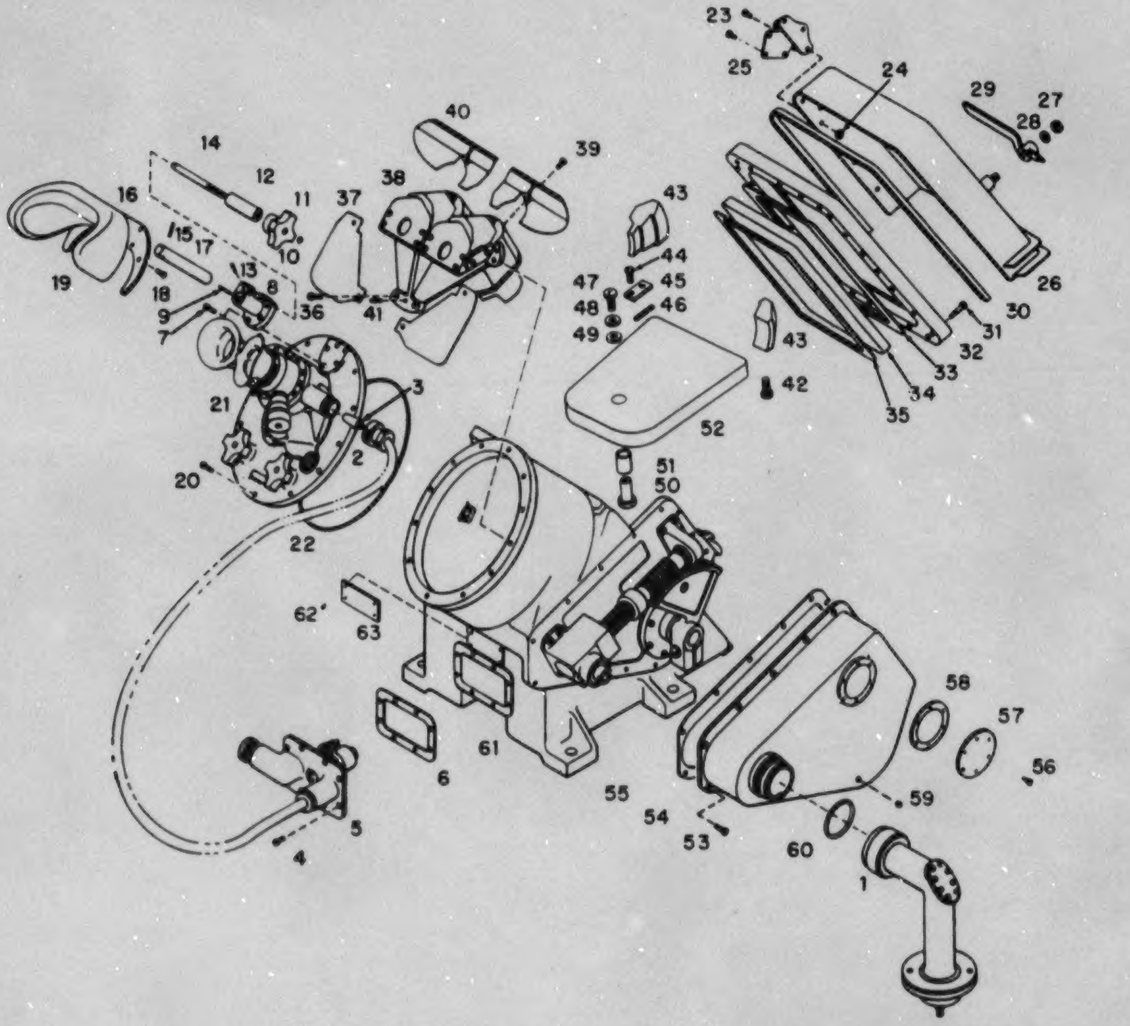
NOTE: The rear and middle auxiliary objectives are eccentric-mounted so the 6X line of sight can be made to correspond with the 10X line of sight. The front auxiliary objectives are in threaded cells for focus adjustment.

For more detailed information on the Mk 100 telescope, refer to OP 1959.

MK 102 AND MK 116 TELESCOPES

You may have thought that just when you have things figured out, we throw something new into the game. The Mk 116 and various Mods of the Mk 102 fall into this category. These 8X, single-eyepiece sights are located on single, rapid-fire gun mounts. Depending on the gun mount and fire control system involved, one or two sights could be used.

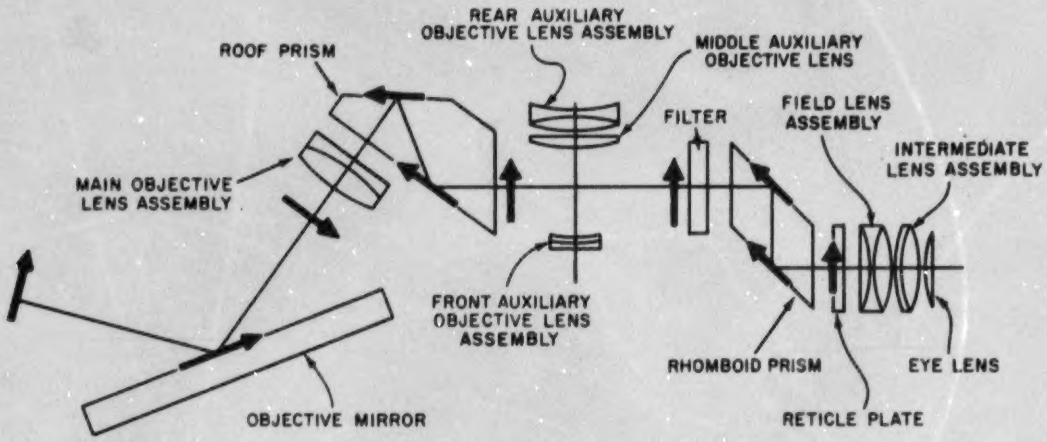
In these sights, elevation (from -20° to +85°) and deflection (30° left or right) of the line of sight is controlled by a synchroservo mechanism



1. Input Drive Shaft Assembly
2. Lamp Socket Mk 9 Mod 0
3. Lamp
4. Screw
5. Illumination Rheostat Subassembly
6. Gasket
7. Screw
8. Headrest Support Bracket
9. Pin
10. Retaining Ring
11. Headrest Knob
12. Headrest Spacer
13. Pin
14. Headrest Clamping Shaft
15. Pin
16. Headrest Support
17. Headrest Adjusting Shaft
18. Screw
19. Headrest
20. Screw
21. Faceplate
22. Gasket O-ring and Cover Assembly
23. Screw
24. Nut
25. Hinge
26. Cover
27. Nut
28. Washer
29. Handle
30. Packing, strip
31. Screw
32. Bezel
33. Gasket
34. Window
35. Gasket
36. Screw
37. Light Shield
38. Objective Mount Assembly
39. Screw
40. Shield Riveting Assembly–Left/Right
41. Pin and Mirror Assembly
42. Screw
43. Counterweight, left
43. Counterweight, right
44. Screw
45. Clamp
46. Gasket
47. Screw
48. Spacer
49. Washer
50. Bolt
51. Packing
52. Mirror
53. Screw
54. Cover
55. Cover Gasket
56. Screw
57. Cover Plate
58. Gasket
59. 1/8-inch Drain Plug
60. Gasket, O-Ring
61. Body Casting (Mirror Tilt Drive is attached; not part of 61)
62. Screw
63. Name Plate

137.562

Figure 11-10.—Telescope Mk 97 Mod 1, exploded view.


REAR AUXILIARY OBJECTIVE LENS ASSEMBLY
ROOF PRISM
MIDDLE AUXILIARY OBJECTIVE LENS
FILTER
FIELD LENS ASSEMBLY
INTERMEDIATE LENS ASSEMBLY
MAIN OBJECTIVE LENS ASSEMBLY
FRONT AUXILIARY OBJECTIVE LENS ASSEMBLY
RHOMBOID PRISM
EYE LENS
OBJECTIVE MIRROR
RETICLE PLATE

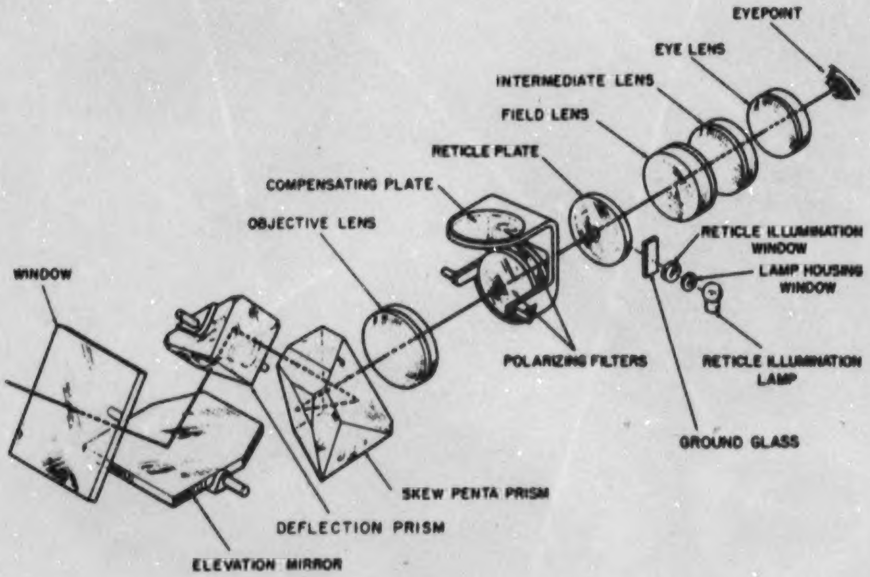
137.563

Figure 11-11.–Mk 100 telescope, optical schematic.

fed by signals from the gun director. There is no mechanical connection between the gun position and the line of sight. In an emergency, or when desired, the gun mount can be locally controlled electrically.

An explanation of synchroservo function is available in Chapter 6, *Opticalman 1 & C*, NAVTRA 10206-series.

The optical system of the Mk 116 and Mk 102 Mods 5 and 6 is shown in figure 11-12. The



148.312

Figure 11-12.–Telescope Mk 102 Mods 5 and 6 and Mk 116, optical diagram.

optical system of the Mk 102 Mod 3 is shown in figure 11-13. These telescopes perform the same function, but the optical system is quite different. For more data on the Mk 102 Mod 3, consult OP 1858.

Functionally, the Mk 102 Mods 5 and 6 and the Mk 116 are interchangeable. You will notice some mechanical and electrical differences when overhauling these instruments.

Figure 11-14 shows a cutaway view of a representative telescope. The optical chamber and servo chamber are separated by an airtight bulkhead, with suitable penetration provided for elevation and traverse shafts. The optical chamber is sealed and pressurized with nitrogen; the servo chamber is sealed but not charged. This arrangement allows access to the servo chamber for adjustment and replacement of components, without disturbing the seal of the more durable optical system. As with the Mk 97 telescope, mounting surfaces machined on the body of these telescopes establish reference surfaces for optical and mechanical adjustments.

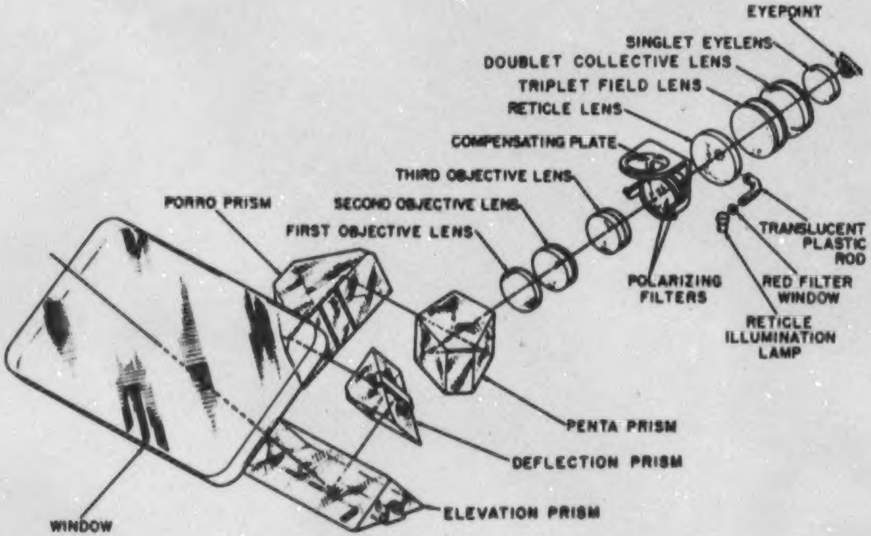
Although you follow a prescribed collimation procedure during overhaul, you can make minor adjustment to the line of sight on the gun mount, using the autocollimator (fig. 11-15).

Each telescope has an autocollimator, located on the inside of the servo chamber cover. The autocollimator consists of a front-surface aluminized mirror and a suitably shaped mount, which fits over the optical chamber window.

To use the autocollimator, attach it to the telescope, energize the telescope, and turn on the reticle illumination.

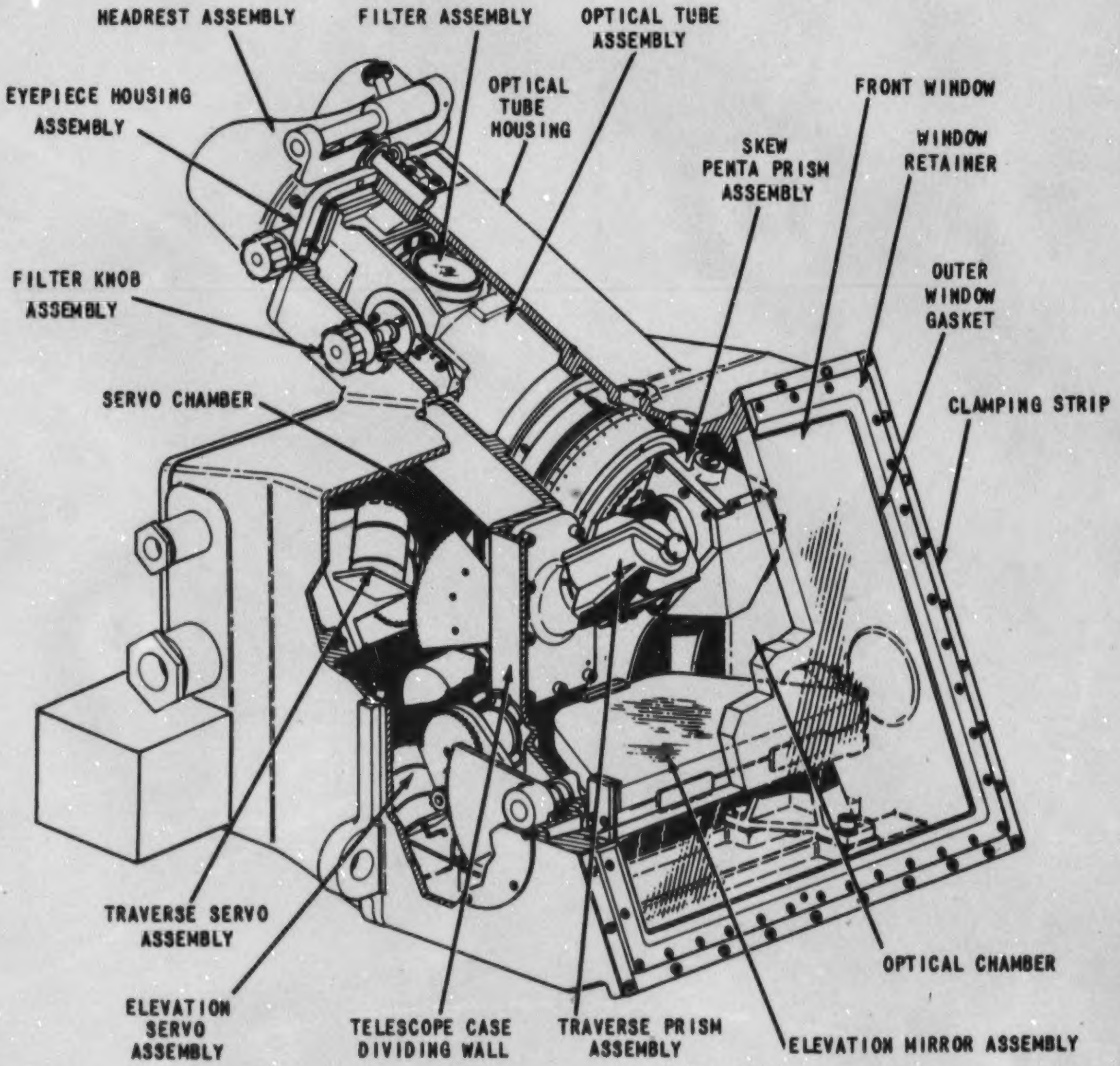
NOTE: It may be necessary to cover the telescope with a dark cloth to exclude bright light.

When you look into the telescope eyepiece, you will see the illuminated reticle and a



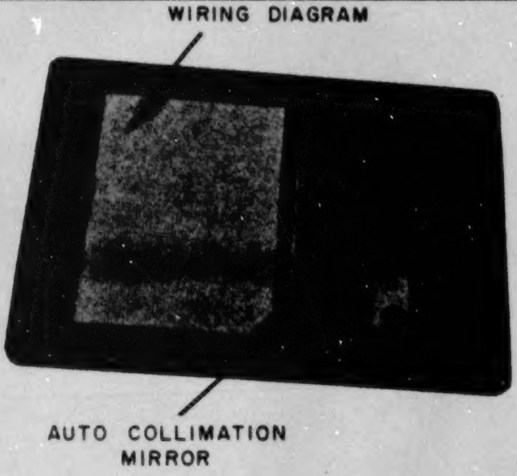
148.314

Figure 11-13.—Telescope Mk 102 Mod 3, optical diagram.



137.584

Figure 11-14.–Telescope cutaway view, typical.



148.313

Figure 11-15.—Rear cover, inside view.

reflected image of the reticle which was transmitted through the optical system, to the autocollimator, and back.

If the reflected image is superimposed on the reticle, there is no problem. If the reflected image is slightly displaced in any direction, you will need to adjust the elevation or traverse (or both) mechanism to establish coincidence.

Complete coverage of technical data concerning the Mk 102 Mods 2, 5, and 6 and the Mk 116 can be found in one or more of the following publications: OP 1858, OP 3651, and OP 4239.

These OP's are updated periodically, and the trend seems to be to change the number of the OP. Even though the information contained in the older OP may be valid, you should always try to use the most recent edition.

339

CHAPTER 12

SUBMARINE PERISCOPES

Since the first attempts to build and operate underwater craft, there has been a need for the occupant(s) to have some way to see out of these watertight vessels. Various names have been used for the devices, but we will use the term "periscope" in this manual.

The first periscope, developed in 1854, was nothing more than a pipe with mirrors at each end to allow the operator to see out. As the science of optics became more exact and the technical means to produce precision lenses were developed, periscopes became more sophisticated. By the time of the first world war, periscopes were quite efficient, and during the 1930's some real progress was realized. These periscopes contained a split image rangefinder and a change of power mechanism. Radar was added a few years later.

In 1958, communications antennas and several improved radar antennas were added, along with a synchroservo mechanism which allowed the periscope to be used for astral navigation like a sextant. Nowadays, it is difficult to keep up with the electronic miracles being added to periscopes.

THEORY AND DESIGN

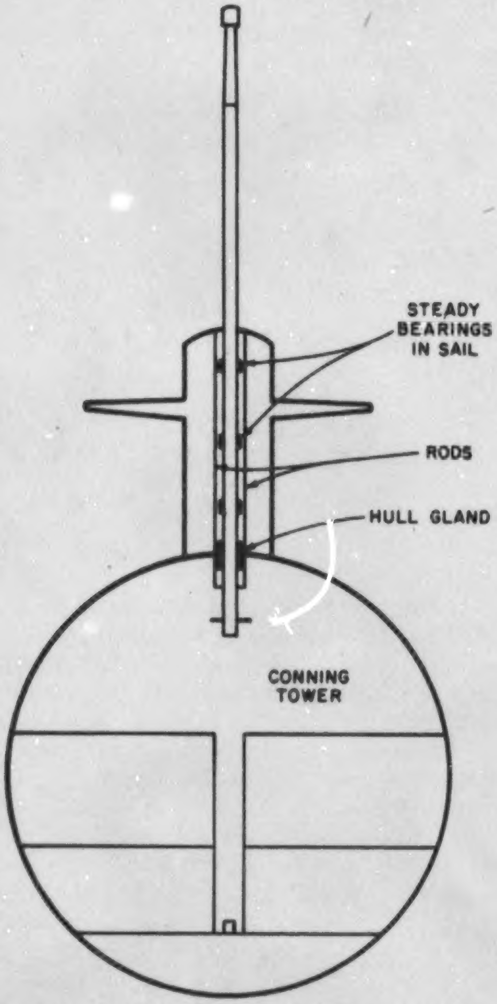
Basically, the periscope is a tube with reflecting elements at the top and bottom to raise the observer's line of sight. But the actual design is not that simple. The periscope designer must solve several special problems brought about by the design of other optical instruments. Compromises must be made between conflicting requirements. Here are some of the problems:

First of all, the periscope has to be relatively long, as you can see in figure 12-1. It must be long enough to rise above the surface while the submarine is still far enough below to be invisible to surface craft. Optical lengths of periscopes run from 36 to 43 feet.

Another important requirement is that the upper head section—the part that sticks out of the water—be as slender as possible to escape detection by the enemy and to create a minimum wake. The wake of the periscope, if seen by the enemy, would not only reveal the submarine's presence, but also would indicate its course. The main outer tube must also be of sufficient size to contain the optics and inner tube sections. Our periscopes are 7.5 inches in diameter with a wall thickness of 1/2 inch.

When the periscope is not in use, it is lowered for protection into a well (fig. 12-1). But when the submarine is maneuvering into attack position, it will use the periscope fully raised, while underway submerged. The periscope, despite its slender construction, must be rigid enough to resist the bending effect of the water pressure that results from its own drag, and the optical system must be designed so the bending effect will not distort or displace the target image.

Another requirement is that the periscope have some means for sweeping through 360° and for elevating the line of sight to check for aircraft. With a modern periscope, the submarine captain sweeps the horizon by rotating the entire instrument. Elevation is provided by a movable right angle prism in the head section.



148.91

Figure 12-1.—Vertical section through a submarine, with periscope elevated.

Since the periscope must be raised, lowered, and rotated, it must pass through an opening in the hull. The design and packing of that opening creates another serious problem. The packing must admit no water into the submarine, even under tremendous pressures, yet it must allow the periscope to be freely raised, lowered, and rotated within it.

The periscope itself must be completely waterproof. The head window and its bezel and the joint by which the head is secured to the upper part of the tube are in direct contact with the sea, so the possibility of leakage through them must be zero. Since the submarine is so dependent on its periscope, the internal optical surface must not fog up. A pressure of 7 1/2 psi of dry nitrogen in the periscope maintains a fog-free condition.

The problems we have listed so far have been mainly mechanical. But there are optical problems, too. The optical system must present a normal, erect image, bright enough to be useful. The field of view must be reasonably wide so the observer can find the target quickly. There must also be some means to determine the range to a target.

The problem of image orientation is not too difficult. Since we need a prism at each end of the optical system to see out, one prism inverts and the other reverts. Then by using a suitable combination of terrestrial and astronomical telescope systems in the periscope, the final image will be normal and erect.

Obtaining a suitable field of view is a major problem, especially when you consider the desired length of a periscope in relation to the entrance pupil which is usually only several inches wide. This obstacle was overcome by placing an upper astronomical telescope in the system backward with a lower telescope in the normal position. (Objective toward the target.)

Suppose the power of the upper telescope is 4X, but the telescope is backward. Its actual power is 1/4X. If an 8° cone of light were able to enter the upper telescope, the 8° field would be reduced to 2° by the reversed telescope $(\text{mag} = \frac{\text{app}}{\text{True}})$. A 2° cone of light can pass through the periscope tube for a considerable distance—approximately 12 feet. The objective of the lower telescope must be placed to take advantage of this cone of light if the light transmission of the periscope is to be effective.

If the power of the lower telescope is 24X, the 2° true field becomes a 48° apparent field $(24\text{X} = \frac{48^\circ}{2^\circ})$. Now to determine the overall power of the periscope, combine the magnification of the upper and lower telescopes.

$$1/4\text{X} \cdot 24\text{X} = 6\text{X}$$

The periscope has fairly good magnification (6X) and a reasonably true field (8°).

The length of a periscope is usually figured as three times the distance between the upper and lower telescope objectives (12 feet):

$$12 \times 3 = 36 \text{ feet}$$

Thirty feet is an impressive length for an optical instrument, but for an attack periscope it should be a little longer to give the submarine a better margin of safety. One way to increase length is to increase the power reduction of the upper telescope, thereby reducing the true field so it can pass through the tube for a greater distance. This was not considered practical because of several other design considerations: (1) the head section of the periscope must be very small; and (2) there must be some means to determine target range. Both problems were solved by adding two more astronomical telescopes above the upper telescope.

Those two telescopes were small in diameter (about 1 inch) and were 1X. (In a 1X telescope, the objective and eyepiece focal lengths are the same, and they have no effect on the true field of the periscope.) A crossline was placed in the upper auxiliary telescope to assist with ranging.

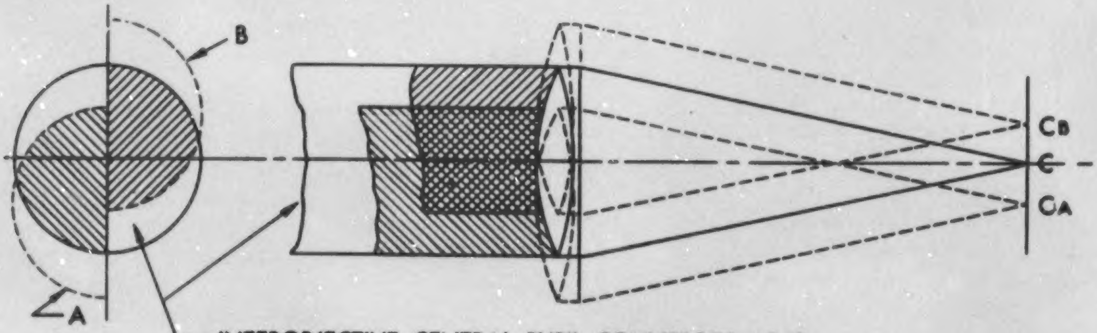
NOTE: In a periscope, the crossline lens is called a telemeter. Lines are etched on the telemeter with a known angular separation so ranges can be estimated.

Now we have a periscope about 42 feet long, with a telemeter and a small head section. With the telemeter placed in the upper auxiliary telescope, even though the tube vibrates when the submarine is moving, the target image and telemeter will move in unison.

We're not finished yet. Range estimation using a telemeter is fine if either the target or observer is reasonably stationary and if there is plenty of ammunition. A submarine can carry only a limited number of torpedos, and the submarine and target are usually moving at angles to each other. Each shot must count.

The accurate ranging problem was solved by splitting the objective of the lower main telescope vertically so both halves would move equally in opposite directions. The observer now has two images of the same object. Figure 12-2 shows the optical principal involved.

The ranging mechanism of a periscope is called a stadimeter. It is attached to the bottom of the scope and consists of a range dial, height scale, and suitable gearing to drive the range dial and split lens gear. To take a range, set the



INTEROBJECTIVE CENTRAL PUPIL CONVERGES AT C TO FORM IMAGE OF CENTER OF TRUE FIELD.

HATCHED AREAS SHOW THE PORTIONS OF THE INTEROBJECTIVE PUPIL WHICH ARE PICKED UP BY THE OBJECTIVE HALVES TO FORM IMAGES OF THE CENTER OF FIELD AT C_A AND C_B

137.539

Figure 12-2.–Lower (split) objective lens ray diagram.

height of the target (waterline to masthead) on the height scale, then operate the stadimeter drive to split the target image. When the masthead of one image is displaced to the waterline of the other image, read the target range opposite the height scale pointer.

As you recall from the beginning of this section, the main portion of the outer tube of a periscope is 7 1/2 inches in diameter. Taking into account the tube thickness and the need for inner tube sections to hold the optics, the diameter of the upper objective is about 5 1/2 inches. Since the lower objective is split and must move in opposite directions to provide ranging, the lens can be only about 4 inches in diameter. Some light is lost as a result, but you still have a reasonably bright image.

The designer has one more small problem to solve; namely, the addition of a change of power mechanism. This is gained by adding a Galilean telescope above the upper auxiliary telescope. This Galilean telescope is 4X, but, when it is in the line of sight, it is backwards. In high power (6X) the Galilean is out of the line of sight. When rotated into the line of sight, the overall power of the periscope becomes

$$1/4 \times 6 = 1.5X$$

which also provides a true field of 32° in the low power position.

Our submarine now has a long attack periscope with a very small head section, an accurate range mechanism, and a choice of 1.5X or 6X. Low power is always used to quickly scan the horizon and air space above, while high power is used to make the attack.

Another factor of periscope design and theory which affects the repairman, and contributed to designer headaches, is that a periscope is charged with nitrogen. Nitrogen has a different index of refraction than air; consequently, light comes to a focus further from a lens when it is in a nitrogen atmosphere.

To fix a periscope, you have to take it apart. Before you take it apart, you have to release nitrogen pressure. When you reassemble and collimate a periscope it is done in air, not nitrogen. Therefore, you must make all collimation adjustments carefully on suitable targets so the completed instrument will perform, as designed, when it is charged to service pressure.

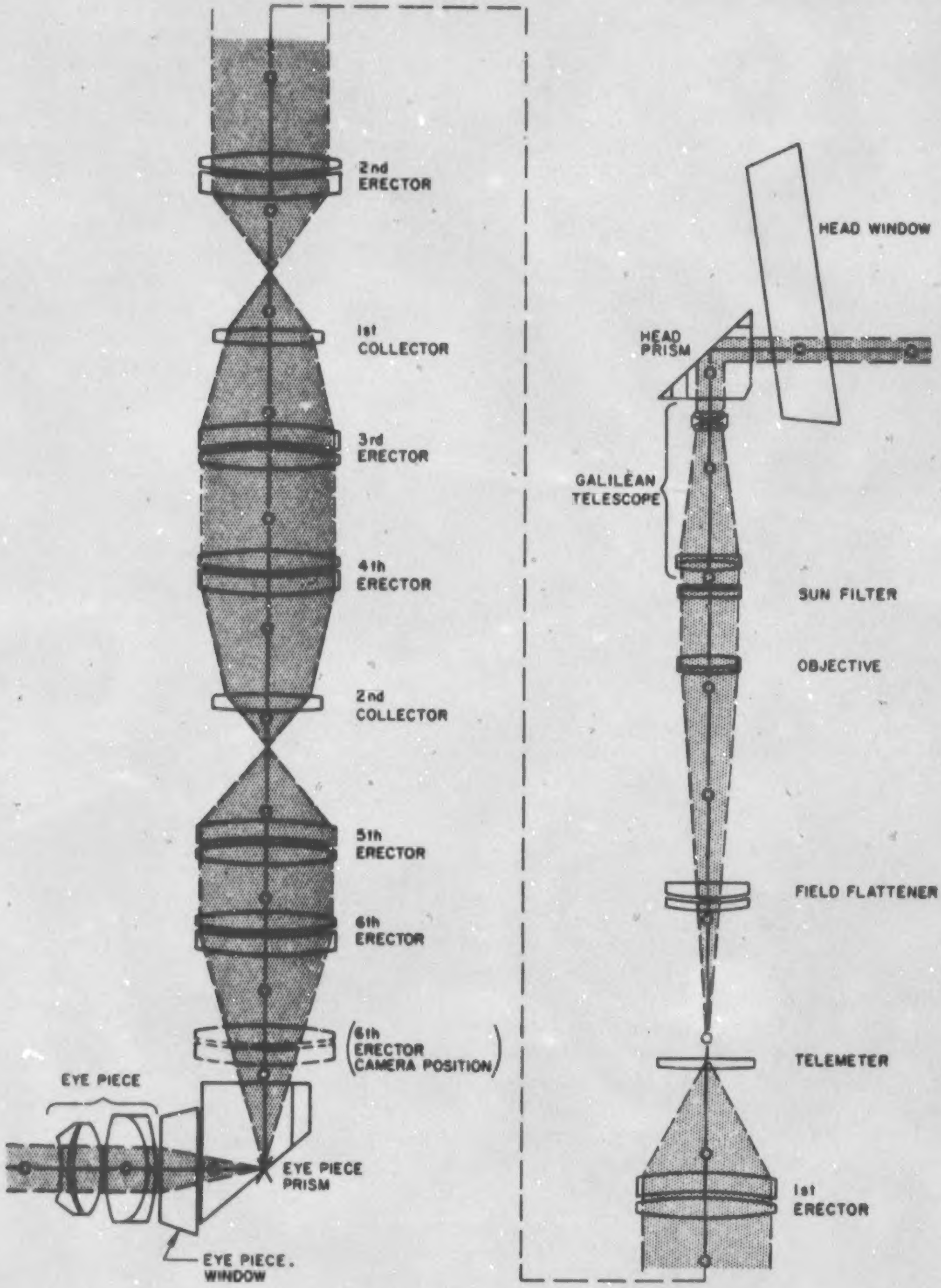
If you think the problems in periscope theory and design are hard to understand, just imagine how difficult it was for engineers to perform all the necessary optical calculations to come up with a compatible optical system composed of five telescopes. This was done in the 1920's without the aid of computers. Except for the theoretical problems involved, periscopes in use since 1958 bear no resemblance to the design explained in the preceding paragraphs.

The optical system common to modern periscopes (fig. 12-3) is a general purpose periscope with no ranging mechanism. Attack periscopes use the same optical arrangement except for a different mounting for the 5th erector and the absence of a sun filter. NOTE: Modern attack periscopes use a solid lens and split lens mounted in a cube so the split lens can be rotated in or out of the line of sight when needed.

Instead of using either three or five telescopes to transmit light and provide an erect image, modern design uses a series of optical relays composed of erectors and collectors. Parallel light passes between the erectors, and the collectors control aberrations and focus available light to the various image planes or erectors. By varying the separation between erectors, a periscope of any desired length can be produced.

These periscopes still use a Galilean telescope for change of power (1.5X and 6X), but this new design will not adapt to the very small head sections required for older periscopes. Since submarines are much faster than before and weapons systems are more accurate, the small head section is no longer necessary.

The 6th erector, shown in alternate position in figure 12-3, has a dual purpose. It can be moved along the optical axis approximately 10 inches. In the upper position, shown by solid lines, it is moved up and down slightly to focus the periscope. When photographs are taken through a periscope, the eyepiece is removed and the 6th erector is moved down to the camera position, shown by dash lines. This moves the image plane outside the periscope to correspond with the film plane of a camera.



148.353

Figure 12-3.–General arrangement of optics.

344

PERISCOPE IDENTIFICATION

Periscopes are not identified by Mark and Mod as other optical instruments. They all have individual serial numbers (called registry numbers), but major identification between different types is by a Design Designation as shown below.

121 KN 36 or 123KA 43.3/HA

The first set of numbers (121 or 123) is an identifying number pertaining to the type of periscope (121 = 8B, 123 = 2D). The first letter (K) refers to the manufacturer, in this case Kollmorgen. The second letter designates the use of the periscope (N for night or observation, A for attack use). The second set of numbers (36 or 43.3) refers to the optical length of the system. HA in the Type 2D design designation means high angle (with the periscope in low power, at the edge of the field you can see directly above you).

The periscopes you will encounter are as follows:

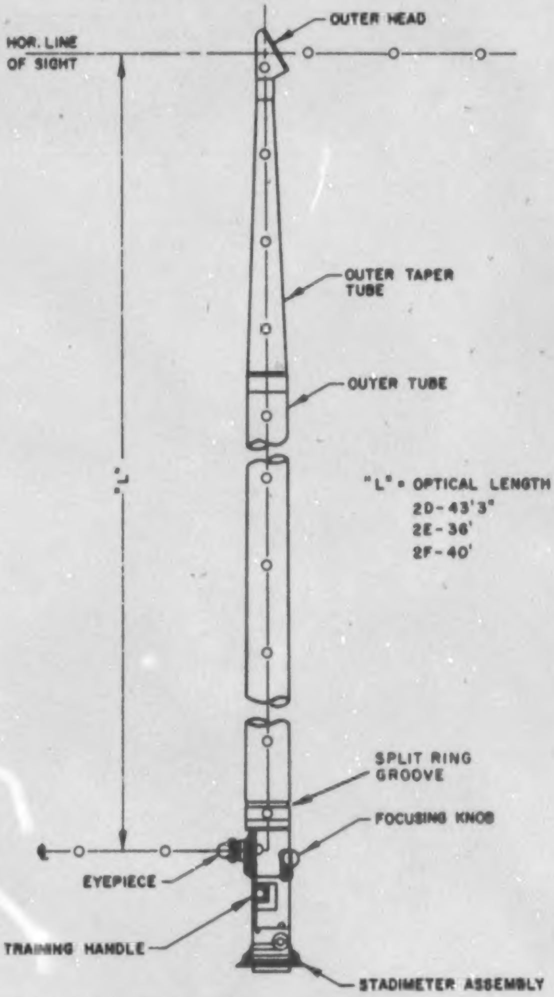
8B 8C 8D 15B 15D 18B 18D	Observation periscopes (radar, ECM, communications antennas)
2D 2E 2F	Attack periscopes (with stadimeter)

All submarines use two periscopes, one for general observation or night use and the other for attack purposes. They may be mounted fore and aft or side by side, depending on the class of submarine. The number one periscope (usually the attack scope) is either nearer the bow or on the starboard side. The number two scope (observation) is second in line or on the port side.

PERISCOPE HANDLING

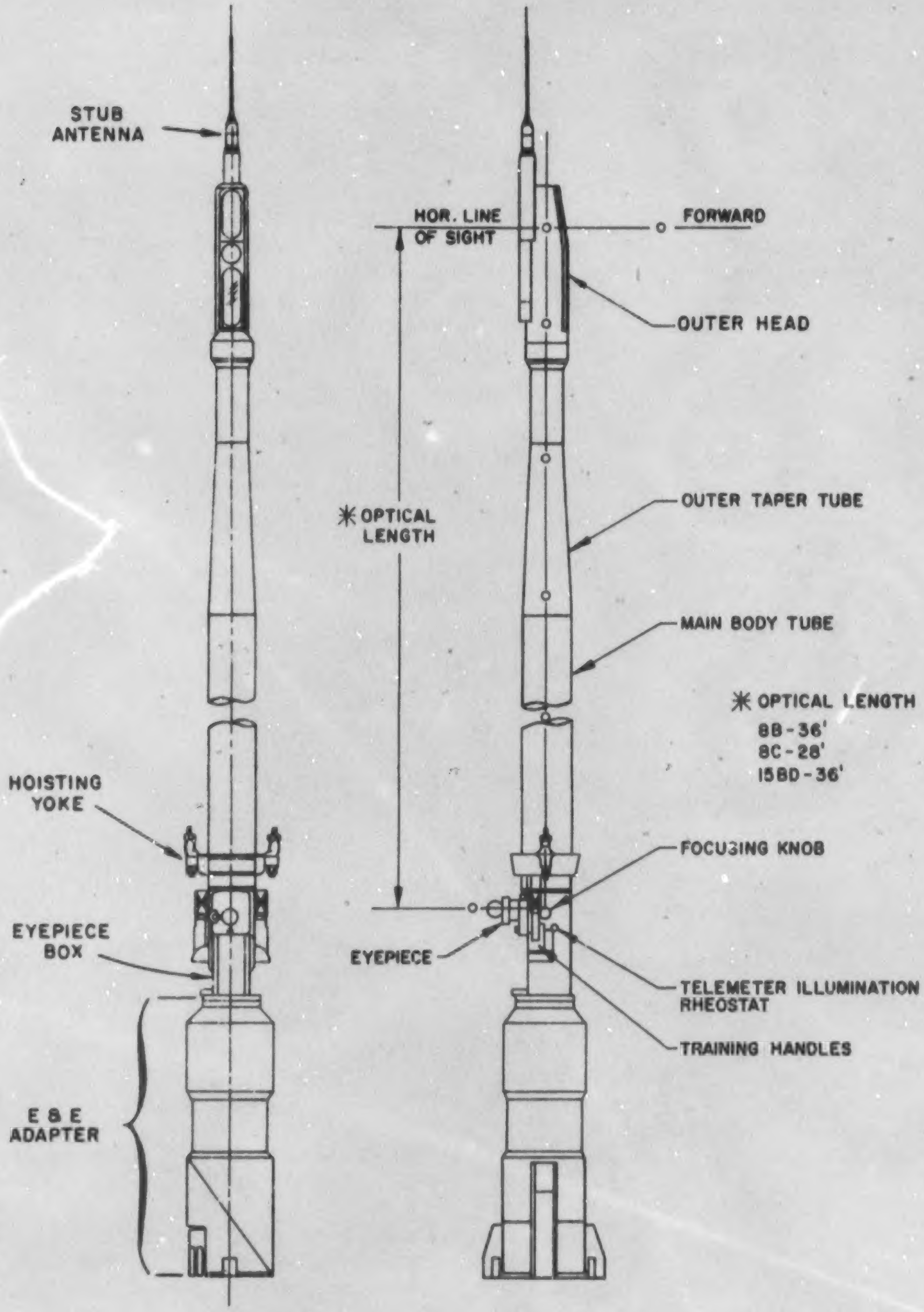
As an Opticalman, you will be responsible for preparing periscopes for removal, pulling them from the submarine, transporting them to your shop, performing necessary repairs, returning them to the submarine, and installing and hooking them up. Considering that a periscope is a 2,000-pound, 40-foot long, greased pole that costs anywhere from 90 thousand to half a million dollars, that is a lot of responsibility, and a challenging job. This section will discuss the correct methods in handling periscopes.

Before getting into any detail, look at figures 12-4 and 12-5 to become familiar with some



134.101

Figure 12-4.—Attack periscope.



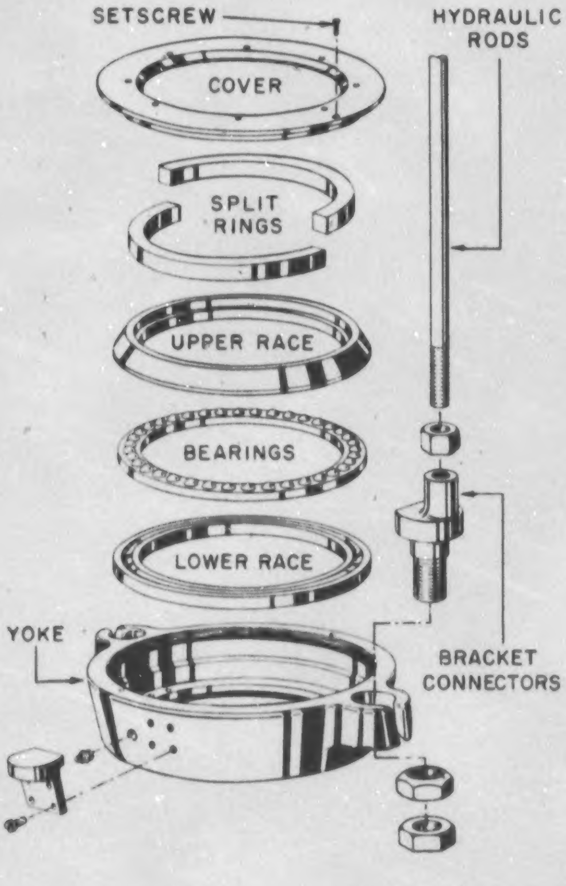
134.101

Figure 12-5.—General purpose periscope.

characteristics of attack and general purpose periscopes.

Before pulling a periscope from a submarine, remove all fittings or accessories which project beyond the 7 1/2-inch diameter of the outer tube. While you are doing this, tools, cap screws, and even the fittings themselves, tend to jump out of your hands and head for the periscope well. You do not want that to happen. People will yell at you, you will be embarrassed, and even worse, you must retrieve the lost pieces.

The weight of a periscope is supported by a hydraulic system and hoisting yoke similar to that shown in figure 12-6. (The hoisting yoke is shown in position in figure 12-5.) Types 2D, 2E, and 2F periscopes use a larger yoke which has a mechanism that transmits target bearing information as the periscope is trained. The yoke is basically a housing for a bearing and race assembly (1, 2, 3). Split rings (4) fit in a split ring groove in the outer tube. (See fig. 12-4.) A shoulder in the upper race fits tightly around the split rings, holds them around the scope, and, in conjunction with the yoke and lower race, holds the scope up. A cover (5) screws into the top of the yoke to lock in the assembly. NOTE: You need a special wrench to install or remove the yoke cover. Notice the setscrew (6). Always check for setscrews.



137.540

Figure 12-6.—Hoisting yoke.

The hydraulic rods (7) are secured in eccentric bracket connectors (8) which are locked into the yoke (9). The bracket connectors are eccentric to allow for minor variations in the separation of hydraulic cylinders installed in some submarines.

Although it is not shown in any of the illustrations in this section, some submarines have a streamlined casing which surrounds the periscope to reduce drag when the scope is raised. This wing shaped casing is called a FAIRING.

Fairings are approximately 12 to 15 feet long, and they can either be attached to the periscope (dependent) or raised and lowered separately (independent). Inside both types are cylindrical bearings to prevent rattling. Teflon bearing blocks fore and aft, located at various points in the sail, cushion the fairing externally. The bearing blocks allow the fairing to be raised and lowered quietly and still take the full force of water pressure when the scope and fairing are raised while underway submerged.

Independent fairings will not usually cause you any difficulties. Dependent fairings, since they are secured to a scope, take special handling when you remove or replace a scope.

PERISCOPE REMOVAL

All operations dealing with the removal or installation of periscopes must be done in a sheltered harbor. Movement of the submarine, while a periscope is partially supported by the steady bearings in the sail, can cause severe damage to both the scope and the submarine. If a tender is doing the job, the sub can sometimes be moved to the lee side. If it is not possible to offer protection in this manner, the job may have to wait for more favorable conditions. However, many times it is absolutely necessary to pull or install a scope regardless of wind or water conditions. When this situation comes up, a very experienced man must be in charge.

You must follow the sequence of events listed below when removing a periscope:

- Notify the submarine duty officer that you are going to pull the scope. When a periscope is removed, there is a 7 1/2-inch hole in the hull, putting the submarine out of commission until the hole is filled. Also, the hydraulic power may be temporarily secured. The duty officer will take steps to provide hydraulics so the scope can be raised and will solve any other problems hindering your scope job.

- Be sure the sail area is clear before raising the scope; you do not want to startle or injure anyone. Cycle the scope up and down several times to be sure the hydraulic system is functioning smoothly; then stop the scope in the observing position.

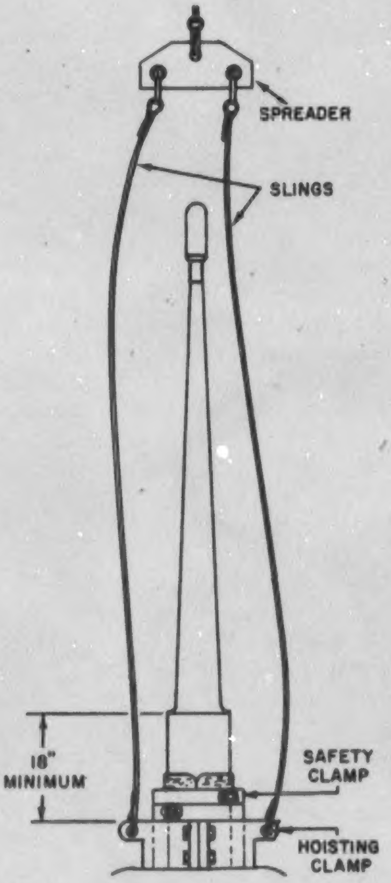
NOTE: Pulling a scope is usually a two- or three-person job; therefore, several of the following steps can be performed at the same time. One or two people can be on the sail clamping the scope, while one or two more are in the control room stripping external fittings from the scope. Teamwork and communication between the sail and control room are essential to prevent errors or omissions.

CAUTION: You must wear an approved safety harness whenever you do any work on top of the sail. Attach the short, heavy line on the harness to any convenient permanent fixture on the sail to keep you from falling.

- With the periscope in the observing position, enough outer tube extends above the sail to provide a suitable area for clamping. In any event the hoisting clamps should be 18 inches or more from the tapered portion of the outer tube. Clean all traces of grease or foreign matter from the outer tube in the area to be clamped. Place two sheets of 150 or 180 grit emery cloth around the scope, smooth side toward the tube.

Figure 12-7 helps to explain the next step. Securely bolt a forged steel hoisting clamp (1) and two safety clamps (2) above it to the scope. See figure 12-7. Place the first safety clamp at a 45° angle to the split of the hoisting clamp, and place the second safety clamp 90° to the first. Attach the slings (3) to a spreader (4) and the hoisting clamp with sturdy shackles.

All equipment used in handling periscopes (shackles, slings, clamps, etc) must be regularly inspected and weight tested to verify safety and condition. After inspection, it is tagged to certify that it passed test and inspection.



148.100

Figure 12-7.—Clamps and slings attached to the outer side.

NEVER use periscope handling gear that does not have a current inspection sticker and NEVER attempt to use any piece of handling gear that you suspect may be defective. Always check each piece of gear every time you use it.

When you have finished clamping the scope, notify the control room. At this time the hydraulic control can be moved to the "lower" position and the clamps will support the weight of the scope.

On many occasions, you will be called upon to clamp a periscope but not pull it, so work can be done on associated components. You will use the same clamps and procedures but you will wrap and seal the clamps and about one foot of the scope above them in plastic to prevent the entry of moisture. This is done to protect the emery cloth between the clamps and scope. When the emery cloth is dry, it provides excellent friction, but, let it get wet, and the scope can slip through the clamps like a greased pig.

- Removing external fittings from periscopes is relatively easy, just remember not to drop anything down the periscope well. If a type 8 is being pulled, remove the stub antenna before the scope is fully elevated and clamped. On general purpose periscopes (fig. 12-5), you must also disconnect the E&E adapter before the scope is fully elevated. NOTE: Be sure all power to the scope is secured before removing the E&E adapter electrical and antenna connections. E&E adapters weigh from 450 to 700 pounds, so a sturdy support must be provided to hold them up.

You must remove an access cover from the E&E adapter before you can disconnect the various connectors between the scope and adapter. Then remove the cap screws holding the adapter to a flange on the bottom of the scope. Lastly, elevate the scope to the observing position and remove the E&E adapter flange.

On all periscopes, the registry number (serial number) is stamped on the focus knob and training handles, and also on the stadimeter of type 2 periscopes. This is done because each periscope is hand fitted at assembly so these components are not readily interchangeable.

Set the right handle to low power, the left handle to zero elevation, and the focus knob to +1.5 diopters before removing them. Switch the illumination control knob to "off" before removal. NOTE: Do not drop the woodruff key when you pull the illumination knob off.

WARNING

PERISCOPE HANDLES HAVE VERY POWERFUL SPRINGS WHICH HOLD THEM UP WHEN THE SCOPE IS NOT BEING USED. THE HANDLES ARE SWUNG DOWN FOR REMOVAL. THEREFORE, THE HANDLE BRACKETS ARE UNDER ENOUGH SPRING TENSION TO BREAK YOUR FINGERS IF YOU HANDLE THEM CARELESSLY.

To remove the stadimeter from type 2 periscopes, first set the "in-out" lever to the "in" position and turn the range knob clockwise to the stop. Now the four captive bolts in the bottom of the stadimeter can be loosened and the stadimeter can be lowered slightly from the scope. Then disconnect the electrical connection between scope and stadimeter. NOTE: The stadimeter is too heavy for one person to support and remove bolts at the same time. GET SOME HELP.

Eyepieces are attached to periscopes with opposed spring-loaded plungers at the top and ball detents at the bottom. To remove an eyepiece, simply pull the plunger knobs out, tip the eyepiece back, and pull it away from the scope.

Keep all external fittings from each individual periscope separated from those of other scopes. Tag each piece and indicate the registry number of the scope you removed it from. It is not uncommon to have fittings from 6 to 10 periscopes in the shop at any one time. Under such conditions parts could be interchanged which could cause problems when the fittings are re-installed.

With all fittings off and the scope resting on the clamps, remove the hoisting yoke. (See fig. 12-6). On general purpose scopes, unscrew the yoke cover, then slowly lower the yoke away from the scope hydraulically. The upper race will usually remain in place and must be tapped off the split rings with a fiber mallet. Carefully pry the split rings away from the scope, then lower the yoke cover off the scope. The bearings and races are now taken to the shop for cleaning and inspection.

Removing the yoke/target bearing transmitter (TBT) from an attack scope is similar to the above procedure with the following exception. A keyway is milled in the outer tube of the scope just below the split ring groove. A key is inserted which drives the TBT when the scope is trained. You must remove this key before you lower the yoke/TBT away from the scope.

After the hoisting yoke is lowered away from the scope, hydraulic power to the system must be secured and the controls must be tagged to prevent operation. If the scope is an attack type, the yoke is usually secured level with the top of the periscope well. For general purpose scopes, the yoke is either secured in a raised position or lowered to the E&E adapter. Where the yoke is secured depends on whether or not the E&E adapter needs work.

- The scope is now free to be pulled from the submarine. The submarine must be on an even keel so the periscope will be as nearly vertical as possible to avoid damage to the scope or steady bearings in the sail. Spot the crane hook directly over the scope, with slings and spreader attached as shown in fig. 12-7. As the crane pulls the scope, one person remains on the sail to attach a steady line around the split ring groove when the scope clears the sail. Someone on the pier or tender handles the other end of the steady line to keep the scope from swinging as the crane moves.

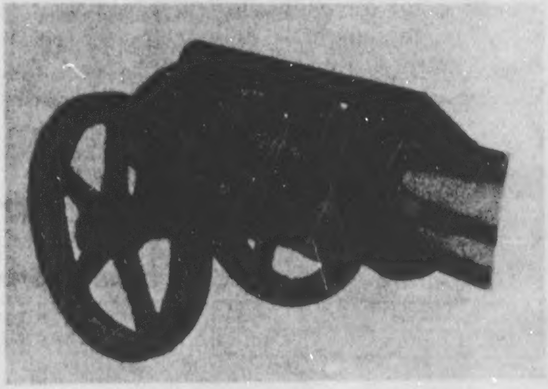
AUXILIARY HANDLING EQUIPMENT

You already know that periscopes are long, heavy, and expensive. You should also know that they are a precision instrument and must be carefully handled to avoid bumps, shocks, or bending. It takes a lot of moving around to haul periscopes between the submarine and your shop or from storage to the submarine. Coordination, training, and proper equipment are necessary.

At some point in the handling procedure, a periscope must be shifted from the vertical to a horizontal position or vice versa. A hinge carriage, similar to that in figure 12-8, is used to make this transition. The carriage can be clamped on a scope when it is in a horizontal position, as shown, or as the scope is lowered vertically toward the deck or pier.

The bottom of the carriage is merely a cushioned socket to protect the eyebox. The rigid frame has provision for a split, hinged clamp which fits around the scope at the split ring groove. When the clamp is tightened around the scope, a split ring or other suitable device keeps the carriage in position. With the hoisting clamp attached and slings and spreader in position, the scope can be lowered to horizontal or raised to vertical by the crane without damaging the eyebox.

Whenever a periscope is in the horizontal position, it should be resting on at least two V-blocks located at the quarter points. (Quarter points are 1/4 the length of the periscope outer tube, measured from each end). The V-blocks can be plain wood, padded metal, or special wheeled dollies. The blocks must be tall enough so the wheels of the hinge carriage will clear the



148.102

Figure 12-8. Hinge carriage at horizontal position.

deck when the scope is in the horizontal position.

To move periscopes in or out of the shop, or storage boxes, a strongback similar to that shown in figure 12-9 is used. The strongback is a rigid I-beam approximately 10 feet long with sturdy split clamps at each end. In the figure, the strongback is shown attached to chain hoists at each end. Normally, a single hoist or crane hook is attached to an eye in the middle of the strongback. When a strongback is used, all other clamps should be removed and the scope should be balanced before tightening the strongback clamps.

If a periscope is to be moved any distance with the strongback, from pier to tender for instance, steady lines must be attached to both ends of the scope to control movement.

While on the subject of handling periscopes, we must comment on storage or shipping boxes. When scopes are transferred, or in some cases stored, special shipping containers are used.

These shipping containers are constructed of heavy gage aluminum, stiffly braced, and provided with heavy wooden skids on the bottom. A tightly sealed lid, composed of two to four interlocking sections, protects the periscope from dust or moisture. The periscope rests on five or six rubber padded semicircular brackets built into the box. A padded clamp, bolted to each bracket, prevents the scope from bouncing or sliding during transport.

Padeyes for lifting scope boxes with slings are welded at the quarter points of the boxes. Two areas for using fork lifts are prominently marked on the boxes. To prevent damage to the boxes and periscopes, never move a shipping container by any method other than those provided.

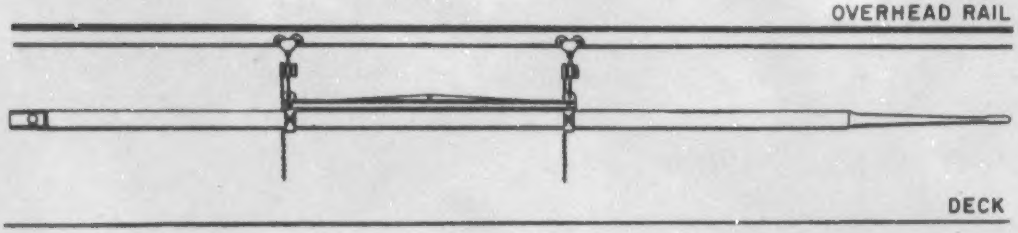
Periscopes are often transported by flatbed truck. Since the shipping container is longer than most truck beds, the eyebox end of the container must be to the front of the truck to allow the lighter taper section of the scope to hang over the end. If the truck driver exercises reasonable care and misses bumps, the scope will be safe.

When a periscope is shipped, the design designation and registry number of the scope are marked on the outside of the box at the eyebox end. Also, all external fittings for the scope are wrapped and secured in the box. (Except for the E&E adapter on general purpose periscopes.)

PERISCOPE PACKING

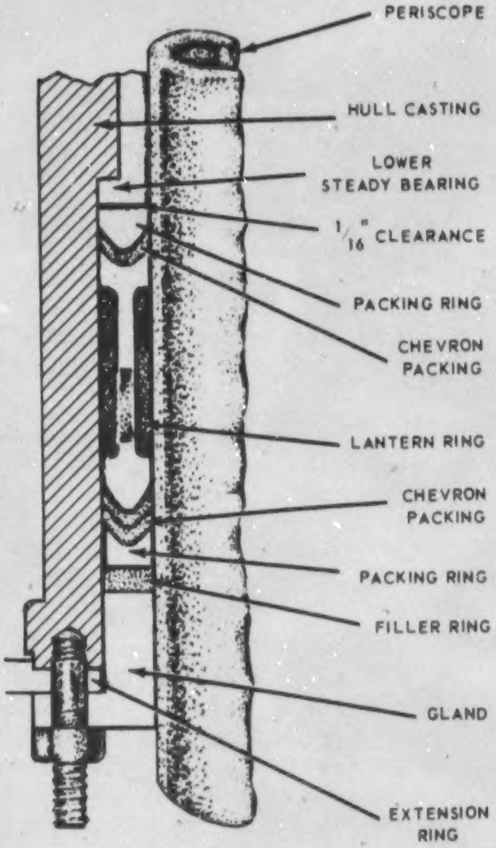
The method for sealing a periscope and hull opening is shown in figure 12-10. By using this particular arrangement, the periscope can be raised, lowered, and trained while the submarine is submerged—with little possibility of leakage. In fact, if all components are properly arranged and perfectly aligned, more water will enter the boat if it is on the surface in a rainstorm than if it were deeply submerged.

Chevron packing is preformed (molded) synthetic rubber available in several sizes (standard and oversize steps). The different sizes are used to take care of variations in the inside diameter of the hull casting. To provide the necessary seal, there can be no cracks or other blemishes anywhere on the surface of the individual rings of chevron packing.



148.104

Figure 12-9.—Periscope supported by strong back and chain hoists.



148.105

Figure 12-10.—Periscope packing assembly.

Other factors which affect the seal of the packing assembly are concentricity of the packing rings, filler ring, and lantern ring; alignment of the lower steady bearing with all other sail steady bearings; and the clearance between the top packing ring and the bottom of the lower steady bearing. The clearance must be between 1/16 inch and 3/32 inch. Seawater pressure acting on the top of the top packing ring through this clearance compresses the engine packing assembly. The deeper you go, the more the pressure; the higher the pressure, the tighter the seal. If any of the bronze rings in the packing assembly are out of round, however, high pressure will distort the chevron packing and probably cause a leak. This causes a wee bit of panic in the submarine and usually results in an optical shop representative waiting on the pier when the boat returns to port.

When a periscope is pulled, the packing must be removed since the scope would tear up the assembly when it is reinstalled. With the scope and packing removed, you have an excellent opportunity to check alignment of the steady bearings and the condition of the hull casting.

Many problems with periscope leakage or difficulty with training are blamed on the packing. The real culprit, however, is usually misalignment of sail steady bearings. The optical shop usually performs this alignment.

Packing can be removed with the scope in place, but this is not the easiest job in the world. You have to raise the scope to the observing position, clamp and strip it, then loosen and carefully drop the hull gland. The metal components of the packing assembly are fairly easy to remove; the chevron packing causes the problems. If it will not slide out easily, you must dig it out with a tool similar to a corkscrew.

PERISCOPE INSTALLATION

Replacing a periscope is NOT the reverse of removing it. In this description we will skip all the steps involved with moving the scope out of the shop and on deck or on the pier. The equipment used has been explained in this chapter; the methods to use vary with conditions present on different tenders.

The first step in replacing a periscope is coordination between the shop, crane crew, and submarine. It takes no more than 15 minutes to get a scope out of your shop and ready to install. Proper scheduling is necessary to be sure the boat is ready to receive the scope and to assure uninterrupted use of the crane. Due to various drills, other priority crane usage, and work by other shops on the submarine, it is often necessary to replace scopes early in the morning or after working hours. The important consideration is to finish the job once it is started.

With all necessary preparations made (submarine informed, external fittings assembled, yoke and packing components ready), the periscope is lifted to a vertical position by the hoisting clamp. NOTE: Location of the hoisting clamp is critical. Different types of periscopes vary in length, and the distance between the control room and sail varies between classes of submarines. You have to know exactly where to clamp the scope so the eyebox will extend the proper distance into the control room.

When the periscope is held vertically, a specially made tapered plug called a bullet is bolted to the bottom of the eyebox. The bullet guides the scope through the sail or fairing bearings. At the same time, a steady line is secured around the split ring groove and passed to a person on the sail. NOTE: If you are on the sail, do NOT forget your safety harness.

The person on the sail has an important job: to help the crane operator spot the scope directly over the hole in the sail, to guide the scope in, and to apply a medium coat of approved grease to the outer tube as the scope is lowered. As you may suspect, this part of your job is dangerous. You do not have any place to stand, the boat is usually moving, and your hands will be covered with grease. That is why you must wear a safety harness.

Once the scope is lowered completely and resting on the clamp, unhook the slings and go help out in the control room.

REPACKING THE PERISCOPE

Repacking the periscope is the next task. The procedure is the same whether you just replaced a scope or are renewing packing in place. At this point, all of the metal rings have been cleaned and checked for concentricity and dings. The chevron packing has been inspected, and the height of the assembled packing has been measured.

NOTE: When the packing assembly is in place, there must be 1/16 to 3/32 inch clearance between the lower steady bearing and upper packing ring. The clearance is the difference between the depth of the hull gland and the stack height of the packing assembly. To obtain this clearance, vary the thickness of the filler ring or substitute different rings of chevron packing.

At least two people are needed to repack a periscope, and you will need several packing sticks. The packing sticks are about 3 or 4 feet long, 1 inch wide, and 3/4 inch thick. Without packing sticks, there is no way you can slip the metal rings or chevron packing into the cavity between the scope and hull casting.

First, slip the upper packing ring around the scope, followed by the top ring of chevron packing. Then use the packing sticks to slide these two components into the hull casting. NOTE: When you slip chevron packing into place, be sure it does not hang up on the lower lip of the hull casting. The lip could be sharp enough to damage the packing.

Now coat the cavity of the lantern ring with grease and slide it into position. Next slip the two lower rings of chevron packing into the hull gland. There may be enough friction between the scope, chevron packing, and hull casting to keep the partial packing assembly in position while you slip the lower packing ring, filler ring, and hull gland into place. If not, use the packing sticks.

After bolting the hull gland into place, use a long .006-inch feeler gage to check clearance between the scope and hull gland. If the feeler gage will not pass freely around the scope, something is wrong. You may need to drop the packing to find the difficulty, or, if you are lucky, you can install the yoke and raise and lower the scope several times to properly seat the packing assembly. In any event, the minimum clearance of .006 inch is necessary to provide proper alignment of the scope, packing assembly, and steady bearings.

The final step in repacking a scope is to hydrostatically test the hull gland. To make this test, one person must crawl into the sail and attach a cofferdam around the scope and upper part of the hull casting.

NOTE: The cofferdam is a special fitting about 18 inches tall and made in two halves. A groove is machined in all mating surfaces to accept a quick-drying sealant.

When the halves of the cofferdam are bolted together, a small amount of water is poured in–then a high-pressure airhose can be attached. This air pressure, acting on the water in the cofferdam duplicates the action of seawater pressure on the periscope packing when the boat is submerged.

EXTERNAL FITTINGS REPLACEMENT

After the ship's force has restored hydraulic power, very slowly move the control lever to "lower," and cycle the yoke down and up several times to remove trapped air in the hydraulic system. NOTE: Perform this step just before replacing a periscope.

Now slip the yoke cover on the outer tube, above the split ring groove, and replace the split rings. With a conventional yoke, slip the upper race on the scope and tap it onto the split rings. Pack the lower race and bearings with approved grease and replace these components in the yoke. Very slowly, raise the yoke into position on the scope until the scope is raised several inches. NOTE: When raising the yoke, you may have to guide it over the bottom of the eyebox. If the yoke hits the eyebox, it could bend a hoist rod. With the yoke in position, pack the yoke cavity with grease and secure the yoke cover.

On a TBT, you do not need to worry about bearings or grease, but you must be sure the keyway on the scope is aligned with the TBT so the key can be reinstalled. Once the yoke is up, tighten the yoke cover the same as a conventional yoke.

Now, remove the bullet from the eyebox and clean all traces of grease from the eyebox and visible area of the outer tube. Then carefully clean the eyepiece window with acetone. Also, remove the clamps at this time.

As you recall from a previous section of this chapter, the external fittings of a periscope were set at specific positions when they were removed (except for the eyepiece). The scope control shafts and external fittings must likewise be matched to facilitate replacement. Be sure the fittings are from the scope you are working on; then replace, secure, and test the fittings.

PERISCOPE REPAIR

As an OM3, you will be responsible for the maintenance of all periscope external fittings. As an OM2, you will be responsible for the complete overhaul of submarine periscopes. We will not go into the detailed procedures for completing an overhaul, but we will explain some of the finer points of construction and adjustment.

EXTERNAL FITTING OVERHAUL

The repair and adjustment of external fittings are just as important as the maintenance of internal optics and mechanical systems. If external components are out of adjustment or damaged, the periscope is essentially useless.

The following fittings for type 2, 8 and 15 periscopes are practically identical: left training handles, eyepieces, blinder attachments, variable density filter assemblies, pressure gage and valve assemblies, and focusing knobs. The right training handles of attack scopes are so similar to left training handles they will not need explanation. Right training handles of type 8 and 15 scopes are identical.

Since external fittings receive considerable handling and some abuse, proper lubrication is essential for performance, and durable paint is necessary for appearance and protection. The preferred lubricant for moving parts is Lubriplate in several grades. Your shop supervisor will specify the type and amount to use on various fittings. The recommended paint is a good grade of semigloss baking enamel. If properly applied, this paint is very durable and will provide an attractive finish.

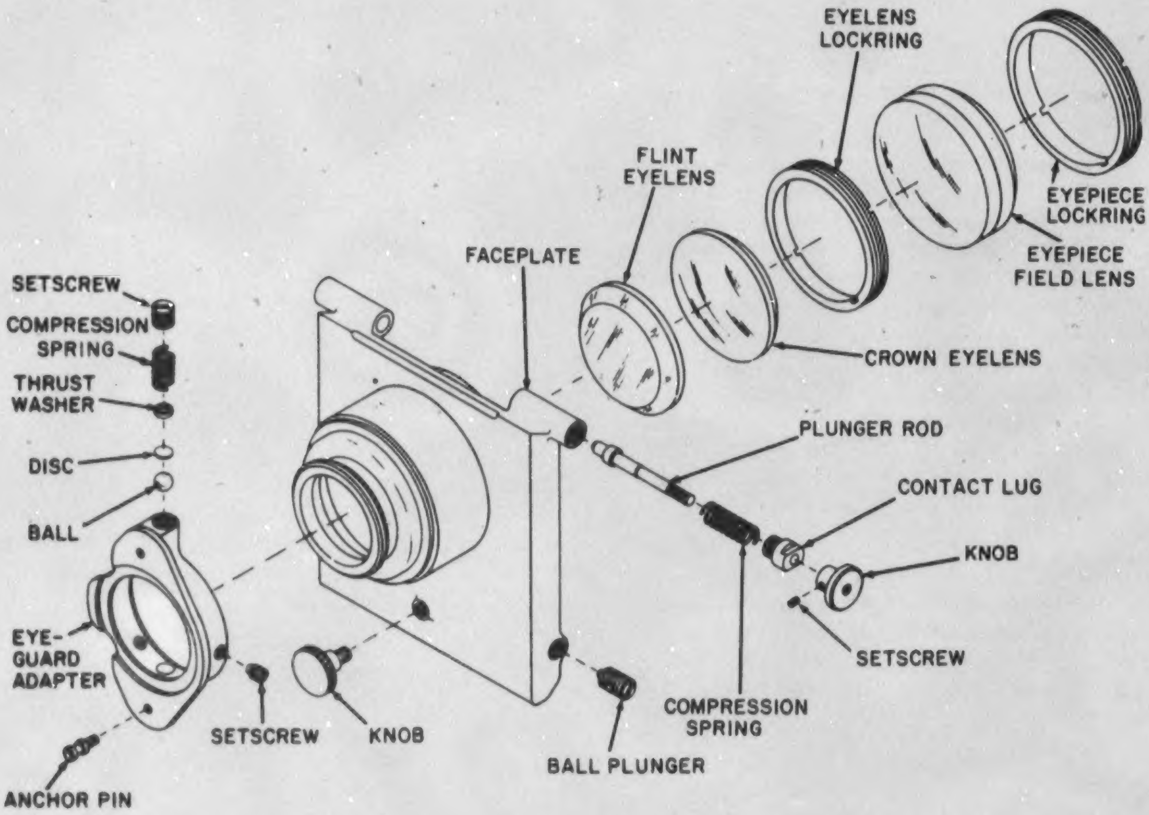
Periscope Eyepieces

An exploded view of an eyepiece and faceplate assembly is shown in Figure 12-11. The eyeguard adapter (8) is free to rotate on the faceplate. Three screws (1) keep the adapter from coming off, and a detent assembly holds it in position.

A spring-loaded plunger assembly (16 through 20) holds the faceplate on the scope eyebox. (Only one plunger is shown.) Part 9 is a self-contained spring loaded detent (only one shown), which holds the faceplate snugly to the eyebox. This arrangement allows the bottom of the faceplate to be pulled away from the eyebox, while pivoting on the detent plungers, so the eyepiece window can be cleaned.

Not shown in figure 12-11 is an eyepiece heater which is built into the faceplate. The heater consists of an electrical contact, which receives power from a power supply pin on the eyebox, and eight turns of resistance wire which are wound inside the faceplate lens cell and sealed with epoxy resin. The heater prevents moisture from condensing on the eyepiece optics.

The two eyelens elements (14, 15) and the field lens (12) are held in the faceplate by retainer rings. When it is necessary to remove the lenses, new shims must be placed between the two eyelens elements. Four shims of 0.001- to 0.002-inch tin foil evenly spaced around the edge provide the required 0.037-inch spacing of the elements.



137.541

Figure 12-11.—Eyepiece and faceplate assembly.

When the eyepiece and faceplate assembly is ready for reassembly, use a drop of Locktite on all threads. This compound prevents the threaded parts from backing out but does not make future disassembly difficult. Also, when you replace the three screws that retain the eyepiece adapter, screw them in tightly and then back them out 1/8 of a turn to provide freedom of rotation without binding.

Blinder Assembly

The blinder assembly (fig. 12-12) is an attachment that fits over two studs on the eyeguard adapter shown in figure 12-11. The rubber eyeguards provide the proper eye distance for viewing through the periscope, and one eyeguard is mounted on a slide to accommodate the viewer's interpupillary distance. Since the eyepiece adapter is rotational and detented, simply by turning the blinder assembly 180° the user can view through the periscope with either the left or right eye.

The most common defects found with blinder assemblies are missing, immovable, or deteriorated eyeguards, or frozen or broken finger lever springs. Since this assembly is quite simple, disassembly and function of components can be easily understood by studying the illustration.

Proper lubrication of the finger levers and springs and between the base plate (13) and blinder retainer (7) will usually result in longer trouble-free service.

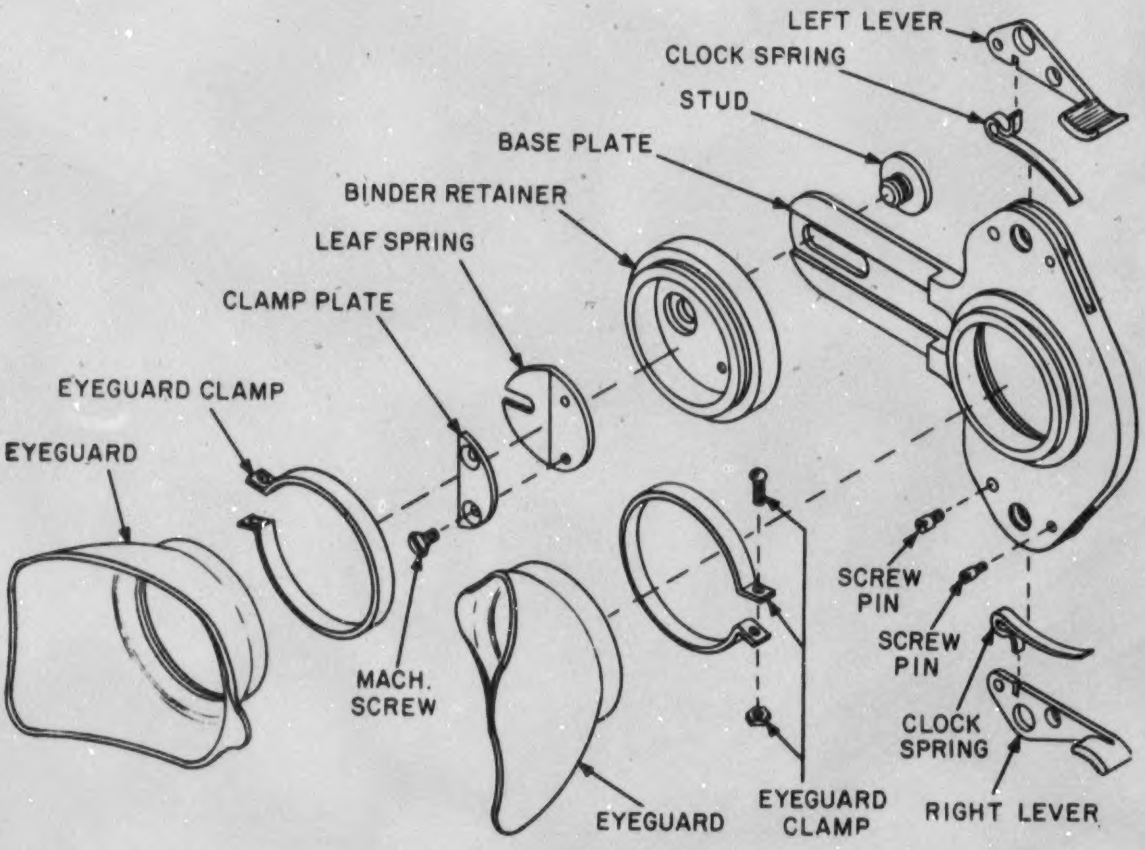


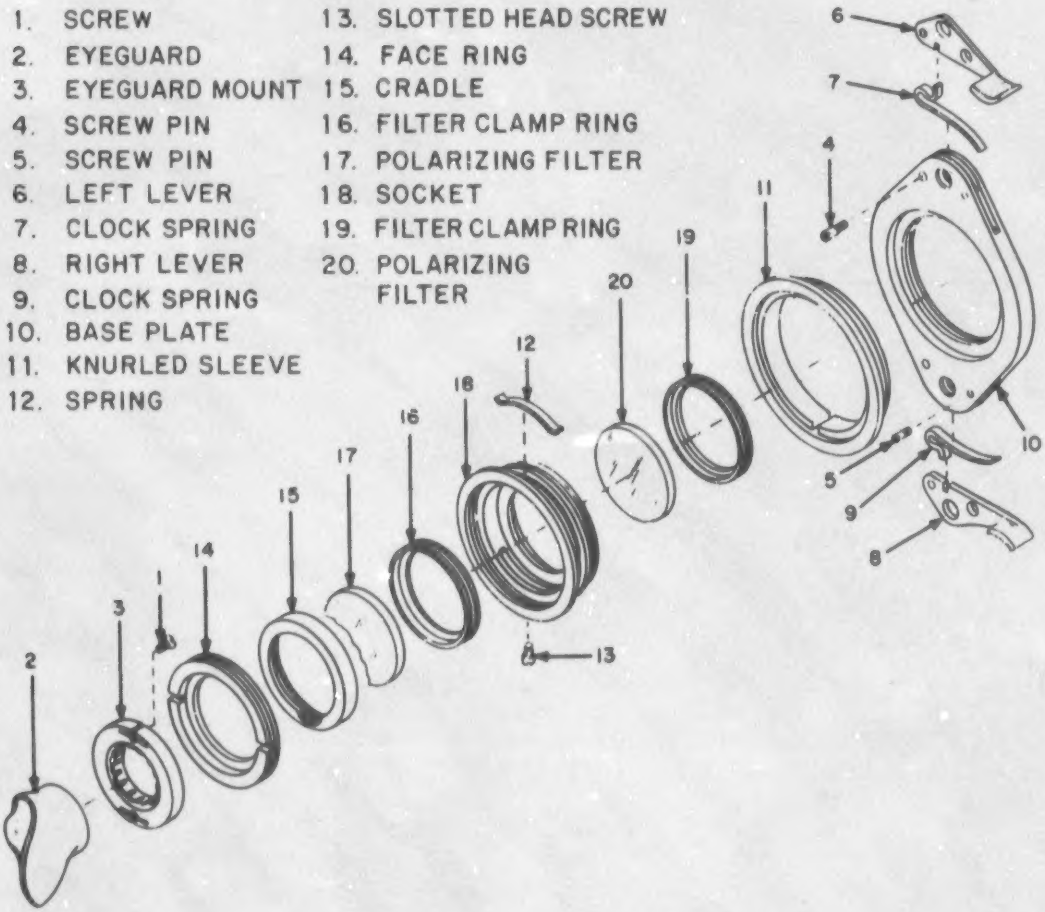
Figure 12-12.–Blinder attachment assembly.

Variable Density Filter Attachment

As you can see from comparing figures 12-12 and 12-13, the arrangement of finger levers and method of attachment of the blinder assembly and variable density filter are identical. Since the construction and operation of the filter assembly is more complicated, however, it can cause you problems if you are not careful.

One way or another, most of the components of the filter assembly are attached to or move around the socket housing (18). Fixed filter (20) and its retainer (19) screw into the front of the socket housing. The movable filter (17) and its retainer (16) are screwed into the cradle (15) which slips into the socket housing. Screw (13) passes through the slot in the socket housing and is attached to the cradle. The slot in the socket housing allows the filter (17) to be rotated 90° to change light transmission from minimum to maximum.

The actuator sleeve (11) is free to rotate when the socket housing is screwed into the base plate (10). When the actuator sleeve is slipped over the socket housing, the head of screw (13) must engage the slot in the actuator sleeve, and the friction spring (12) must be depressed slightly to allow the parts to mate.



137.543

Figure 12-13.—Variable density filter attachment assembly.

357

The face ring (14) screws into the rear of the socket housing and retains the cradle and movable filter, but allows the cradle to rotate. The eyeguard mount (3) and eyeguard, when they are secured in the face ring, complete the assembly.

If an eyeguard is in poor condition, remove it by pulling it away from the eyeguard mount. To replace an eyeguard, carefully pry open (toward the center) the equally spaced clips before inserting the new eyeguard. NOTE: The clips, which are an integral part of the eyeguard mount, are made of brass. Therefore they can be bent only once or twice before breaking. It is common practice to pry the clips apart just enough to accept a new eyeguard and then press it in place in the eyeguard mount.

As you can see in figure 12-13, there is a horizontal and vertical slot at the top and bottom of the eyeguard mount (3). At the intersection of the slots, there are tapped holes to accept bevel head friction screws (1). These screws are installed from the rear, as shown in fig. 12-13, but are not tightened until the eyeguard mount is slipped into the face ring. The shoulder on the face ring prevents access to the screwheads, so the ends of these screws are slotted for the jeweler's screwdriver. When the eyeguard is properly oriented, turn the friction screws counterclockwise from the front to spread the slots in the eyeguard mount to lock the eyeguard mount in the face ring.

Now that you are familiar with the function and relationship of parts of the filter assembly you need a few more hints to properly assemble the filters. Both the fixed and movable filter have short lines scribed at the top and bottom to indicate the proper orientation of the axis of polarization. Both filters should be assembled with these marks toward the periscope eyebox. When the filter assembly is completely assembled and the index marks of both filters are aligned vertically, maximum light transmission will be realized and glare will be reduced. Turn the actuating sleeve clockwise. The movable filter should rotate 90° and reduce light transmission to zero. Proper orientation of the fixed filter is quite easy, but you may need to partially disassemble the whole filter assembly to establish the proper relationship between the movable filter, cradle, and socket housing.

The moving parts of the filter assembly are quite closely fitted. Any burrs or distortion would be detrimental to smooth operation. Apply just enough lubricant to mating parts to provide smooth operation, but not so much that it will contaminate the filters.

Pressure Gage and Valve Assembly

The pressure gage and valve assembly (fig. 12-14) is common to all modern scopes except for some of the earlier type 8 periscopes. The assembly is secured to the inside of the lower door on the eyebox (to be shown later). Not shown in the figure are the 12 screw holes which are factory drilled through the flanged portion of the gage housing (16).

This assembly is quite sturdy and usually troublefree, but the gage (6) does eventually wear out, and leaks can develop around the various O-rings. The most common source of leakage is from the shutoff valve (13).

The pressure gage reads from 0 to 30 psi, but periscopes are pressure tested to 50 psi. Therefore, the shutoff valve must be used quite often to secure pressure to the gage before it is damaged by excessive pressure.

Whenever you must disassemble this assembly, replace all O-rings. You must also be extremely careful during disassembly and in removing old O-rings to avoid damage to O-ring seating surfaces.

Focusing Knob Assembly

The focusing knob (fig. 12-15) is more complicated than you might expect, but it does more than provide a focus range of +1.5 to -3 diopters. Since the 6th erector (focusing erector) of a periscope can be moved about 10 inches, the focusing knob must be able to provide the necessary movement, with suitable internal stops to prevent overtravel or damage to related components.

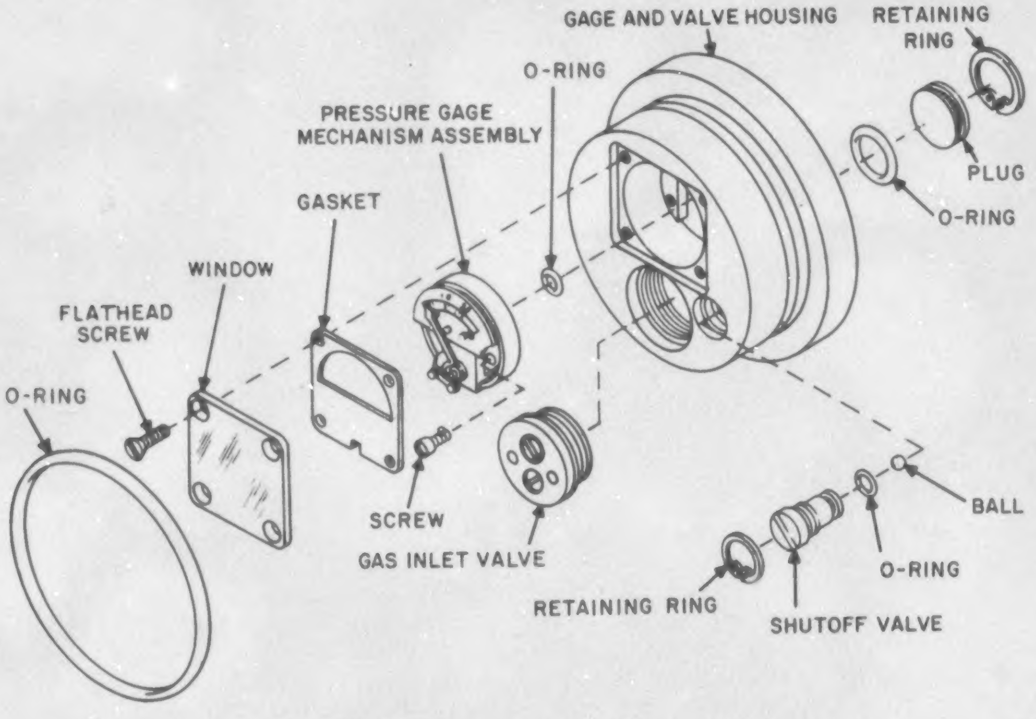


Figure 12-14.—Pressure gage and valve assembly. 137.544

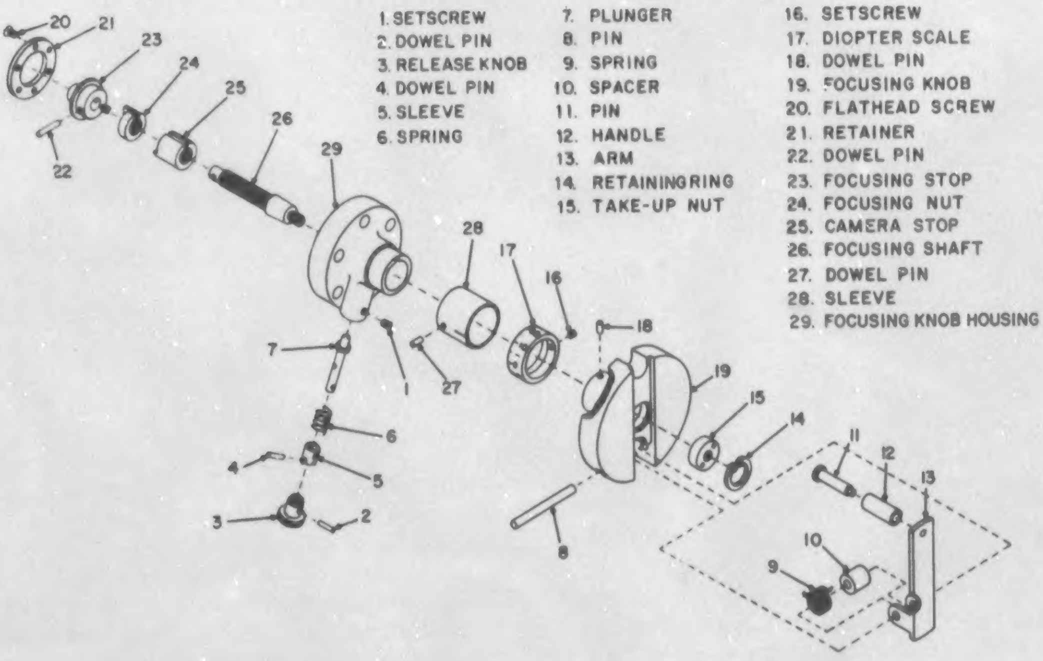

1. SETSCREW
2. DOWEL PIN
3. RELEASE KNOB
4. DOWEL PIN
5. SLEEVE
6. SPRING
7. PLUNGER
8. PIN
9. SPRING
10. SPACER
11. PIN
12. HANDLE
13. ARM
14. RETAININGRING
15. TAKE-UP NUT
16. SETSCREW
17. DIOPTER SCALE
18. DOWEL PIN
19. FOCUSING KNOB
20. FLATHEAD SCREW
21. RETAINER
22. DOWEL PIN
23. FOCUSING STOP
24. FOCUSING NUT
25. CAMERA STOP
26. FOCUSING SHAFT
27. DOWEL PIN
28. SLEEVE
29. FOCUSING KNOB HOUSING

Figure 12-15.—Focusing knob assembly. 137.545

As a starting point in understanding this assembly, you will need to know the limits of travel available. With the focus knob turned all the way to the stop, clockwise, the diopter scale should read +1.5 diopters. With the knob turned approximately 260° counterclockwise, the diopter scale should read -3. Now pull out the detent plunger (2 through 7) to disengage the focusing stop; turn the focus knob counterclockwise to a stop, which cranks the 6th erector down to camera position. NOTE: From the +1.5 diopter stop to the camera stop takes approximately 6 1/2 to 6 3/4 turns.) The spring-loaded handle (shown in dash lines) can be extended to provide rapid action for this operation.

To disassemble the focusing knob, there is no specified starting point. Use the following steps as a guide.

1. Remove the detent plunger assembly by backing out screw 1, which also secures bushing 5 in the focusing knob housing (29). Further disassembly of the plunger assembly, if necessary, is apparent in fig. 12-15.

2. Turn the focusing knob clockwise to the stop, extend the handle (13) and back the nut (15) out to contact the retainer ring (14). The inside of the focusing knob has a tapered socket which matches the tapered end of the focusing shaft (26). Backing nut 15 out against the retainer should separate the focusing knob from the focusing shaft. If not, tap the focusing knob with a fiber mallet to release it.

3. Remove the six screws from the retainer (21) and withdraw the focusing shaft and stops as a unit (22, 23, 24, 25, 26). Do not disturb the relationship of these parts unless repair is necessary.

The focusing shaft (26) is machined with a left hand thread. The focusing stop (23) is pinned to the focusing shaft. The camera stop (25) is positioned against the shoulder on the focusing shaft. When this assembly is all together, pin 18 in the focusing knob engages the slot in the camera stop. Consequently, when the focusing knob is turned, parts 23, 25, and 26 turn together. The focusing nut (24) rides up and down the focusing shaft and is prevented from turning by a tab which engages a slot in the focusing knob housing (29).

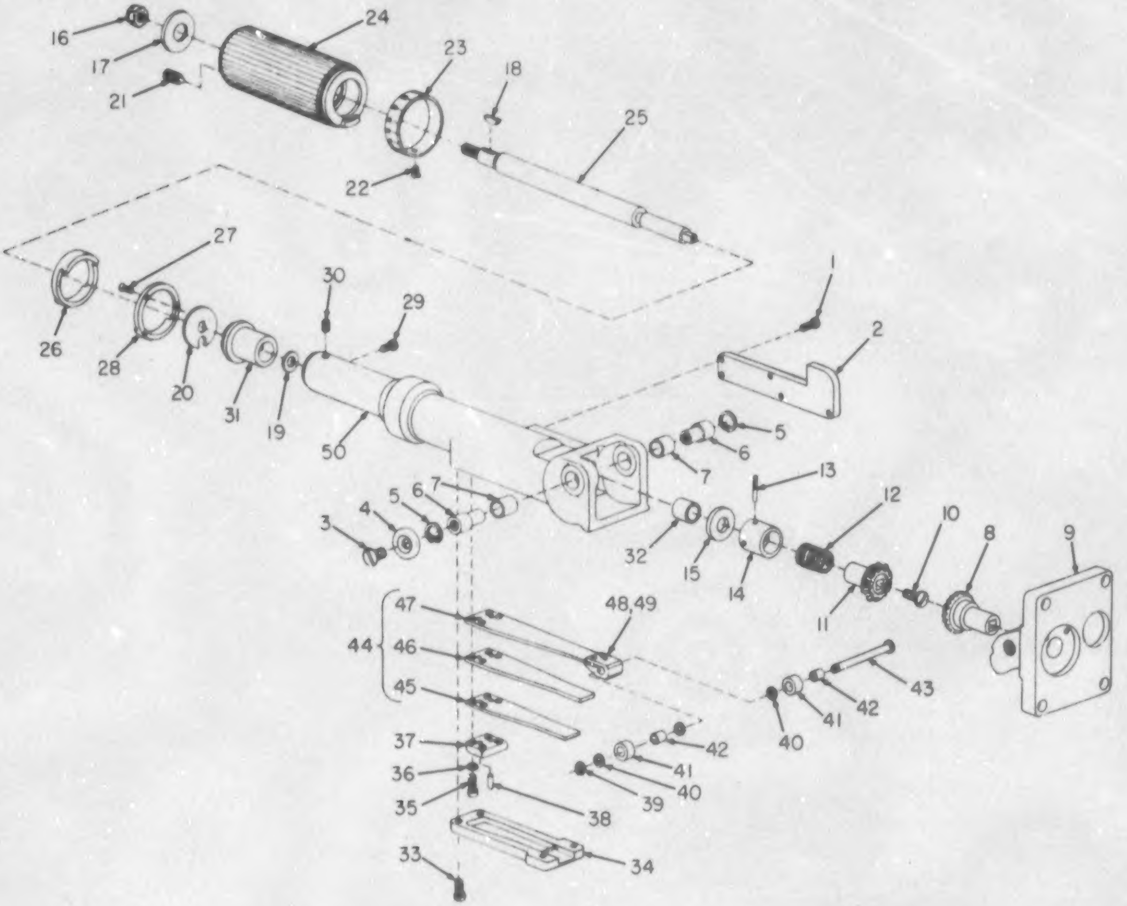
For the stops to function properly, the length of the camera stop (25) is critical, as is the initial placement of the focusing nut (24). If you replace any component of the focusing shaft or stops, you will need to do some machining to obtain the proper travel and engagement of the focusing nut. Also, machine the tab on the focusing nut to provide at least .040-inch engagement with the lip on the camera stop.

Notice that the short threaded section of the focusing shaft (26) is slotted for a screwdriver. This feature allows you to make some external adjustment of the stops when the focus knob is attached to the periscope. Simply by backing nut 15 against stop ring 14 to release the focus knob, you can hold the knob and turn the focusing shaft with a screwdriver to properly place the stops. Then reseat the focusing knob. If the diopter ring (17) does not align with the index mark after the previous adjustment, loosen setscrew 16 and reset the diopter ring. NOTE: Anytime you make repairs to any portion of the focusing mechanism, either in the periscope or focusing knob assembly, you must make the focus knob adjustment just explained as part of the scope collimation procedure.

Left Training Handle Assembly

The training handle shown in figure 12-16 is generally representative of left training handles found on type 2, 8, and 15 periscopes. Any differences between handles used on the various periscopes are usually found in pivot bushings (3 through 7) and in the handle stops and detents (26, 28, 31). NOTE: The handle shown is from the type 15 periscope.

Complete disassembly of the training handle is seldom necessary. It is much more sensible to disassemble only to the extent necessary to make needed repairs. Common wear points



1. SCREW, SELF-LOCKING
2. COVER, LEFT TRAINING HANDLE
3. SCREW
4. CAP
5. RING, RETAINING
6. PIN, PIVOT
7. BUSHING
8. GEAR, CLUTCH BEVEL (INNER)
9. BRACKET, L.H. TRAINING HANDLE
10. SCREW
11. GEAR, CLUTCH BEVEL (OUTER)
12. SPRING, CLUTCH
13. TAPER PIN
14. COLLAR, SHAFT
15. WASHER, THRUST
16. NUT, SELF-LOCKING
17. WASHER
18. KEY, WOODRUFF
19. WASHER, THRUST
20. WASHER
21. BALL PLUNGER
22. SCREW, ROUND HEAD
23. BAND, GRADUATED, LEFT HAND
24. GRIP, LEFT TRAINING HANDLE
25. SHAFT, CONTROL
26. STOP RING, INTERMEDIATE
27. SCREW, FLAT HEAD
28. STOP RING
29. SCREW, SELF-LOCKING
30. SETSCREW
31. DETENT BUSHING
32. BEARING, NYLINER
33. SCREW, SELF-LOCKING
34. COVER, TRAINING HANDLE
35. SCREW, SPECIAL
36. WASHER, LOCK
37. BLOCK, SPRING RETAINER
38. PIN, DOWEL
39. RING, RETAINING
40. WASHER, THRUST
41. ROLLER
42. BEARING
43. SHAFT, CAM FOLLOWER
44. SPRING LEAF ASSEMBLY
45. LEAF SPRING, BOTTOM
46. LEAF SPRING, MIDDLE
47. LEAF SPRING, TOP
48. BRACKET, LEAF SPRING
49. RIVET
50. HINGE, LEFT TRAINING HANDLE

137.546

Figure 12-16.—Training handle assembly.

include the inner and outer bevel gears (8, 11), the pivot pins and bushings (6, 7), and the elevation stops and detent bushing (26, 28, 31).

If it is necessary to separate the hinge (50) from the handle bracket (9) you must release tension on the spring leaf assembly (44). Remove the cover (34) and back off evenly on the four screws (35) which secure the spring retainer block (37). When replacing the leaf spring assembly, you must torque the special screws (35) to no more than 40 inch-pounds. NOTE: When working on a periscope handle with the leaf spring assembly in place, be extremely careful that the handle bracket does not snap shut on your fingers.

The relationship of parts in the left training handle and disassembly sequence is readily apparent in figure 12-16. If you replace the inner or outer bevel gears, or any component of the elevation stops, you will need to replace the handle on the periscope to check for proper operation and adjustment as needed.

Right Training Handle Assembly

Right training handles of type 2 periscopes are so similar to the left handle that no illustration will be presented. After making repairs to the right handle, you must be sure that shafts and gears are properly aligned and that stops are set, so that the periscope shifts properly between high and low power. The stops are very important. Overtravel of the handle can stretch the steel tapes that shift the Galilean lens cubes, and undertravel can partially shift the cubes and block out part of the field of view.

The right training handle common to types 8 and 15 periscopes is shown in figure 12-17. This handle does more than change power. A sextant mark switch (60) activates a remote recorder to record the elevation of celestial objects, and two switches on the switch actuator assembly (38) activate a torque motor in the E&E adapter to assist with training the periscope. Pushing one switch with your thumb turns the scope to the right, pulling the other switch with your index finger turns the scope left.

Also included on the switch actuator assembly is the high power filter release. When the scope is in high power, the release can be pushed toward the scope, and the grip can be turned slightly to drop a very dark filter into the line of sight. The filter enables the operator to use the sun as a navigation aid.

A wiring harness assembly (11), secured to the handle bracket, contains a receptacle and all the necessary wiring to connect the various switches in the handle to a mating plug on the periscope eyebox.

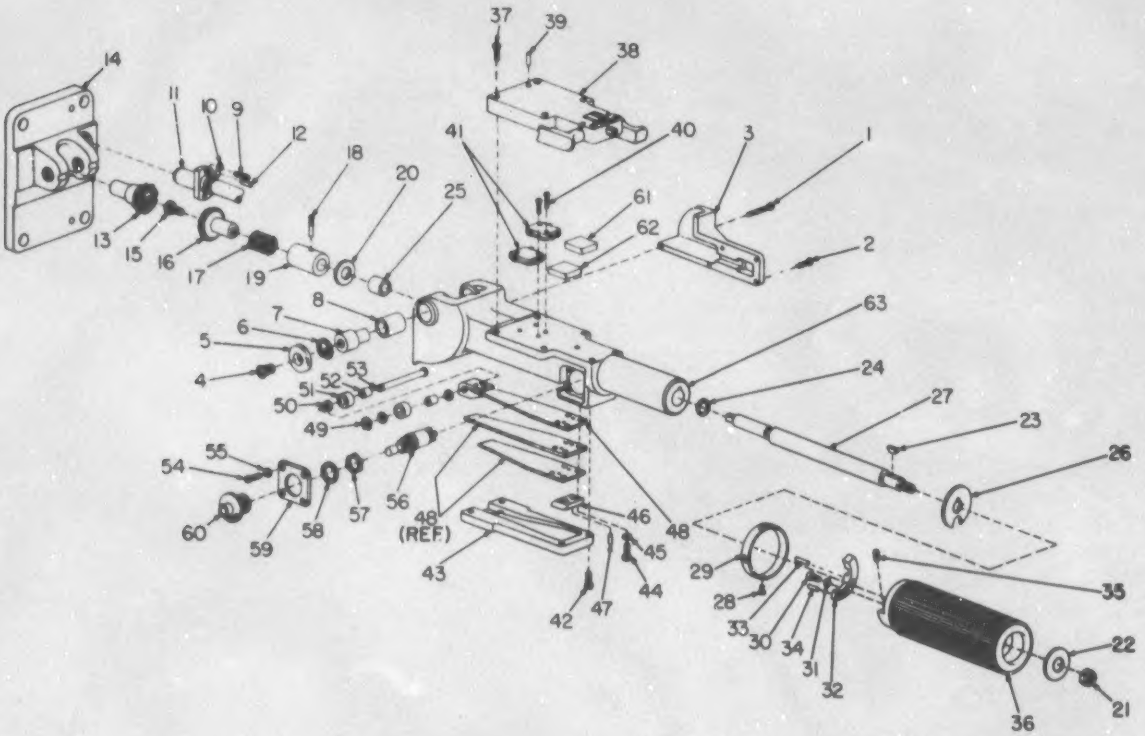
The mechanical portion of the right training handle is essentially the same as a left handle, so it should not be a problem. You will need a multimeter to check wiring and switch function, however. If you are not familiar with multimeters, once your shop supervisor explains their function, you can learn to troubleshoot a variety of problems in a short time.

Stadimeter Dial and Drive Assembly

A very simplified schematic of the stadimeter attached to the bottom of type 2 periscopes is shown in figure 12-18. The stadimeter is heavy but very precise. Shafts and gears are supported by preloaded thrust bearings to prevent end shake, and the special couplings between the stadimeter and eyebox compensate for misalignment between the shaft axes. An adjustable stop on the stadimeter drive shaft allows full travel of the split lens and range dial but prevents overtravel.

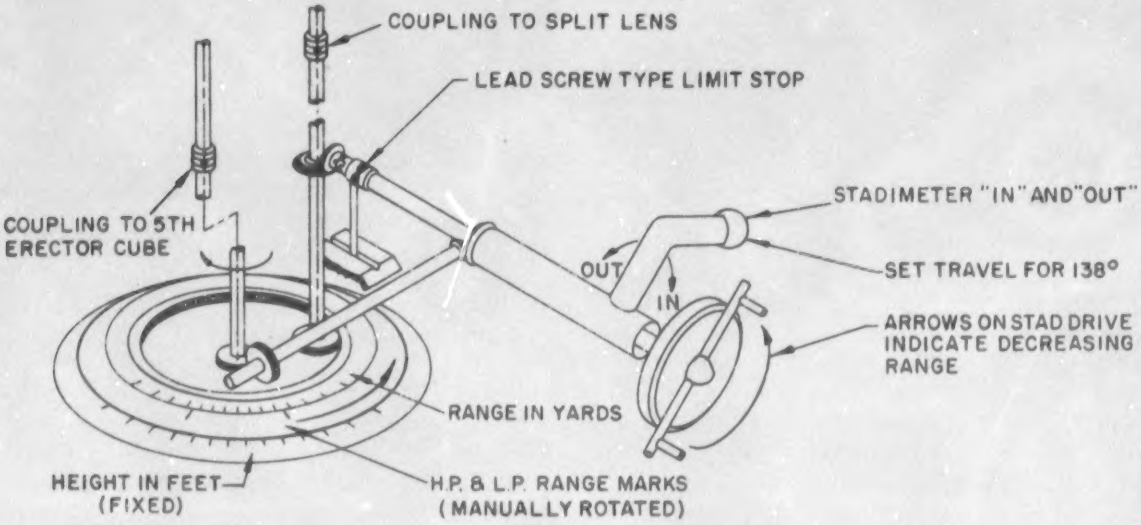
A wiring harness in the stadimeter provides illumination to the dials, but the stadimeter is strictly mechanical. The inside of the stadimeter is packed with grease to provide lubrication and to prevent the entry of moisture. If repairs are necessary, this grease can be quite messy.

Since clearances and adjustments to the stadimeter and split lens cube (5th erector) are very critical, you should follow the repair procedure outlined in NAVSHIPS 324 0487 if you perform any work on either the 5th erector assembly or stadimeter. During periscope collimation, you must attach the stadimeter to the scope to be absolutely certain that all



1. SCREW, SELF-LOCKING
2. SCREW, SELF-LOCKING
3. COVER, RIGHT TRAINING HANDLE
4. SCREW, FLAT HEAD
5. CAP
6. RING, RETAINING
7. PIN, PIVOT
8. BUSHING
9. SCREW, CAP
10. WASHER, LOCK
11. WIRING HARNESS ASSEMBLY with PLUG, FEMALE
12. PIN, DOWEL
13. GEAR, CLUTCH BEVEL (INNER)
14. BRACKET, TRAINING HANDLE, RH
15. SCREW
16. GEAR, CLUTCH BEVEL (OUTER)
17. SPRING, CLUTCH
18. TAPER PIN
19. COLLAR, SHAFT
20. WASHER, THRUST
21. NUT, SELF-LOCKING
22. WASHER
23. KEY, WOODRUFF
24. WASHER, THRUST
25. BEARING, NYLINER
26. WASHER
27. SHAFT, CONTROL
28. SCREW
29. BAND, GRADUATED, POWER CHANGE
30. SCREW, CAP
31. WASHER
32. STOP, INDEXING
33. PIN, DOWEL
34. PIN, DOWEL
35. SETSCREW, SELF-LOCKING
36. GRIP, RIGHT TH
37. SCREW, SELF-LOCKING
38. SWITCH ACTUATOR ASSEMBLY
39. PIN, DOWEL
40. SCREW, PAN HEAD
41. SWITCH, MICRO
42. SCREW, SELF-LOCKING
43. COVER, TRAINING HANDLE
44. SCREW, SPECIAL
45. WASHER, LOCK
46. BLOCK, SPRING RETAINER
47. PIN, DOWEL
48. SPRING, LEAF
49. RING, RETAINING
50. WASHER, THRUST
51. ROLLER
52. BEARING
53. SHAFT, CAM FOLLOWER
54. SCREW, FILL HEAD
55. WASHER, LOCK
56. SWITCH, PUSH
57. NUT (Part of 56)
58. WASHER, LOCK (Part of 56)
59. PLATE, SWITCH
60. HOUSING, SWITCH (Part of 56)
61. FILTER, MARK SWITCH
62. FILTER, FORWARD AND REVERSE SWITCHING
63. HINGE, RIGHT TRAINING HANDLE

Figure 12-17.—Right training handle assembly. 137.547


COUPLING TO SPLIT LENS
LEAD SCREW TYPE LIMIT STOP
STADIMETER "IN" AND "OUT"
COUPLING TO 5TH ERECTOR CUBE
OUT
IN
SET TRAVEL FOR 138°
ARROWS ON STAD DRIVE INDICATE DECREASING RANGE
RANGE IN YARDS
HEIGHT IN FEET (FIXED)
H.P. & L.P. RANGE MARKS (MANUALLY ROTATED)

148.352

Figure 12-18.—Stadimeter dial and drive assembly.

components of the ranging mechanism are functioning properly.

PERISCOPE MAINTENANCE

Since a periscope is a very complicated instrument, and because there are numerous different types, we cannot possibly offer detailed repair procedures in this text. Even an experienced repairman must use job sheets or the appropriate technical manual for these tasks.

The first step in periscope repair is to perform a casualty analysis check to determine exactly what is wrong with the instrument to establish a practical extent of disassembly. Each type periscope (2, 8, 15) requires a different casualty analysis procedure due to the different optical, mechanical, and electronic components in each system. Casualty analysis sheets are not necessarily standard either. Each ship or shore repair facility usually produces its own. The important consideration is that all checks must be in a logical sequence as thoroughly as possible to detect any defect or deficiency.

The most essential factor in periscope repair, other than correct procedures, is cleanliness. You have learned from previous pages that external components can be greasy and dirty. However, once a scope is opened, the environment must be scrupulously clean. An optical shop is traditionally one of the cleanest spaces in a ship, but, during some cleaning and assembly operations, a super clean area is required.

The "Clean Room" should be located as close as practical to the periscope rail where disassembly/reassembly is accomplished. The room can be large enough for one or more people to work comfortably, and it will contain electrical outlets, excellent lighting, and, in some cases, running water and compressed air lines. The primary requirement for the clean room is a constant supply of filtered air delivered at a pressure slightly higher than the rest of the optical shop. The positive air pressure prevents entry of dust or other foreign particles.

At least two filters are used in the clean room air supply. One is similar to a household heating or air-conditioning filter. The final stage filter must be a cellulose-glass absolute filter capable of trapping particles as small as 0.5 micron (a micron is 1/1000 millimeter). In addition to the positive pressure filtered air supply, workers in the clean room should wear lint free uniforms and head covering. Needless to say, smoking is prohibited in the clean room.

The methods for cleaning optical and mechanical components of optical instruments, which were discussed in previous chapters, generally apply to periscope maintenance. The only difference is that much more care must be taken in working on a periscope since it is so much more difficult to remove from a submarine, disassemble, repair, reassemble, cycle, and install. Your objective is to do the job correctly and carefully the first time.

Inner Tube Removal

Once you have determined the problems in a periscope, you can begin disassembly. The following steps, while not complete in all details, will serve as a general guide.

- Release gas pressure.

- On type 8 and type 15 periscopes, disconnect the various antennas from the head section before pulling the inner tube.

- Roll the scope so the head window is facing up. Set the scope in low power with the head prism at zero elevation.

- Check the brass main coupling between the eyebox and outer tube for setscrews. Remove setscrews and unscrew the coupling with a special main coupling wrench. NOTE: Threads on the outer tube are right hand, threads on the eyebox are left hand, and corresponding threads are machined in the coupling. When the coupling is rotated counterclockwise, viewing from the bottom of the eyebox, the inner tube is withdrawn from the outer tube approximately 3 inches. A key is attached to the eyebox just above the threaded portion. The key mates with a keyway in the inner tube to assure alignment of the inner and outer tubes at assembly.

When you unscrew the main coupling, attach a chain hoist to the eyebox to prevent the inner tube from sagging as it is withdrawn. NOTE: Figure 12-19 shows a few sections of inner tube and the arrangement of control shafts and tapes of a type 2 periscope. The type 8 and type 15 inner tube structure is similar except for the absence of the split lens mechanism and the addition of various waveguides and antenna cables.

While smoothly withdrawing the inner tube from the outer tube, support the inner tube at various points to prevent sagging and binding. This support can be in the form of individual straps and chain hoists, but most shops use lightweight strong backs similar to that shown in fig. 12-9. Place the straps around the inner tube without binding tapes, control shafts, or electric/electronic components.

When the inner tube is clear of the outer tube, set it on a periscope rail alongside the rail holding the outer tube or, as in most ships, set the outer tube in blocks on deck to make room for the inner tube. NOTE: As the inner tube is being shifted to the periscope rail, it must be handled very carefully to avoid springing or bumping. At least three people are needed to move the inner tube, and absolute coordination of movement is essential.

Just before setting the inner tube on the periscope rail, position V-blocks under six to eight flanged joints between inner tube sections to safely support the inner tube.

- As soon as the inner tube is pulled from the outer tube, cover the opening in the outer tube with masking tape to prevent entry of lint or dust. NOTE: In some rare instances, a periscope can be repaired without pulling the inner tube, if the defect is in the upper tube sections. This is possible because the tapered section of the outer tube is joined with a coupling similar to the main coupling at the eyebox.

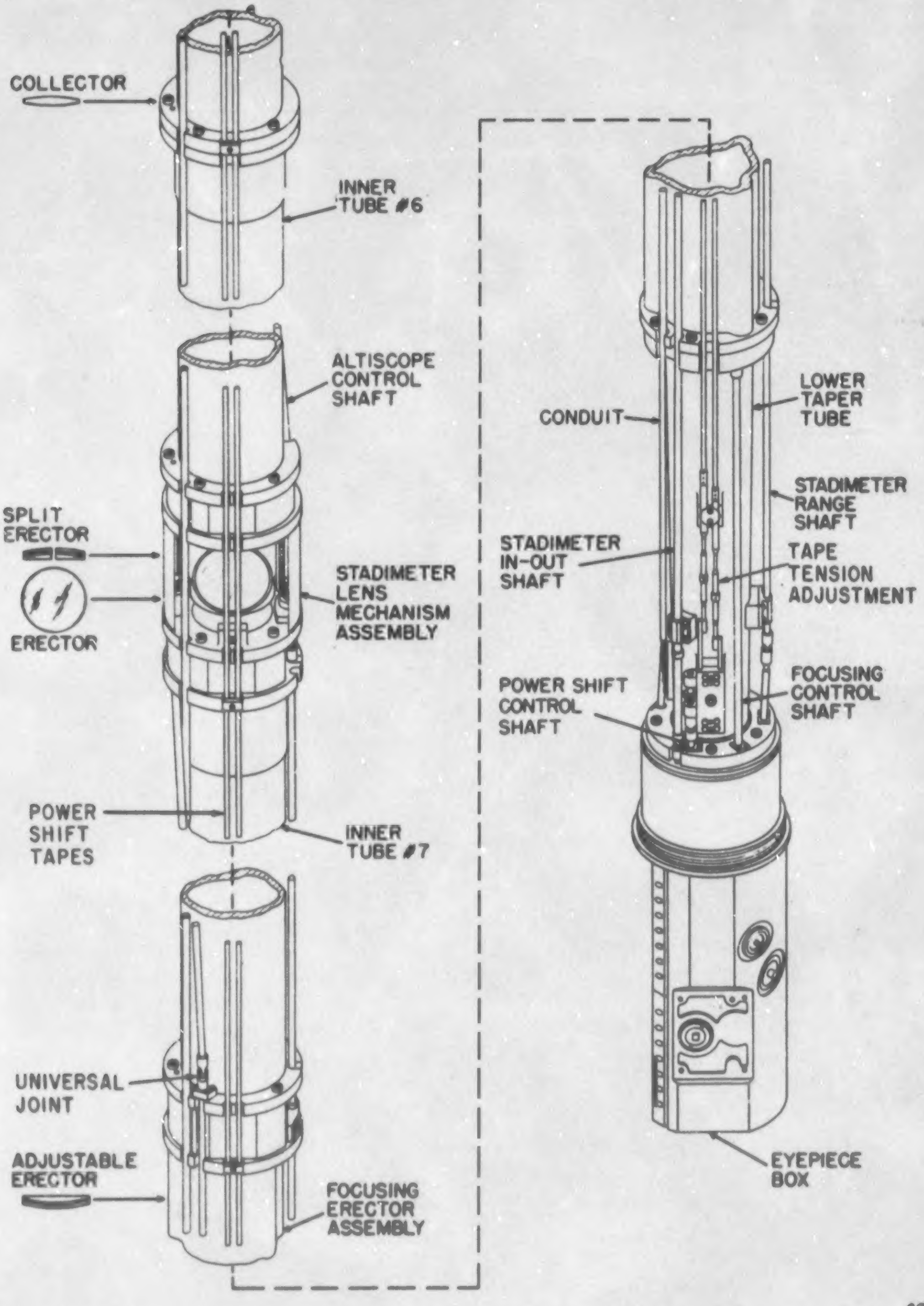


Figure 12-19.—General arrangement of inner structure.

366

Disassembly and Repair

Periscopes seldom wear out; they are just too well made. Entry of moisture, careless maintenance, oil vapor on optics, failure of electrical/electronic components, unauthorized tampering, and misuse in service are the predominant causes of failure. Periscopes have been used for ice picks and can openers with disastrous results, and, if subjected to excessive speeds while raised, a good portion of inner tube disassembly may take place automatically. Discounting all problems caused by "the other guy," periscopes require an annual overhaul as a preventive measure.

It is hard to imagine the degree of precision in periscope construction unless you have actually worked on these instruments. For instance, when the left (elevation) handle is rotated slightly, the rotation is transmitted through 4 spur gears, 2 sets of bevel gears, numerous universal joints, 35 to 40 feet of shafting, a self-centering coupling to a worm and sector attached to the head prism mount. When the handle is turned, the head prism moves; lost motion or backlash is practically nonexistent.

You must use the same degree of care and skill in your work on periscopes as the manufacturer used in designing and constructing the instruments. The way to obtain this skill is through experience in assisting with periscope repair jobs.

Periscope repair is seldom possible by an individual. You need three hands–or you need to be in two places at once. A team of three or four people usually strips an inner tube. No starting point is specified, but the following steps need to be performed before inner tube sections can be separated.

- On type 8 and 15 periscopes, remove the retainers which secure the radar waveguide and various antenna cables or conduits to the inner tube flanges. These components are usually lifted off as a unit and set in racks under the periscope rail. NOTE: Portable, compartmented parts trays hold the various nuts, bolts, washers, and retainers.

- Remove electrical wiring from terminal blocks on appropriate inner tube sections and place the wiring harness in racks on the periscope rail.

- Remove shafting for the focusing erector and head prism. On type 2 periscopes, remove split lens in-out shaft and range shaft.

NOTE: Many of the components listed above are shown in figure 12-19.

CAUTION: Shafts are separated at universal joints. The shaft and joint sections are held together with taper pins or, in some cases, a key and keyway. You must firmly support the U-joint while tapping out the taper pin. Tape the pin to the U-joint if it is to be reused.

- Release tension on the power shift tapes. (See fig. 12-19.) Remove the tapes from the power shift racks above the eyebox and at the head section. Now, you can pull the tapes from the inner tube guides and roll them carefully in a 6- or 7-inch roll.

Now, you can separate the various inner tube sections, as necessary, to gain access to the optics and focusing erector, skeleton head, and, in the type 2, the split lens mechanism.

Inner tubes are held together with six self-locking socket head cap screws per section. Support assembled sections in V-blocks, as you remove the shorter sections, to avoid dropping any portion of the inner tube structure. Any sudden drop, even though it may only be 3 inches, is often enough to chip a $200 lens. As you pull each inner tube section apart, cover the open ends with masking tape to keep out lint or dust.

Inner tube sections are numbered to show their location in the periscope, since some of them are so similar that improper reassembly is possible. The shop that performs the first overhaul on a scope numbers the inner tube sections prior to disassembly.

- Carefully remove and mark the various lenses. (Refer to fig. 12-3.) The high power objective and erectors are mounted in adjustable cells. The telemeter, field flattener, and collectors are retained in their respective tube sections. NOTE: The sixth erector (focusing erector) is a separate unit. The fifth erector in type 2 periscopes is the split lens mechanism.

- Disassemble the eyebox component assembly. A type 15 eyebox is shown in figure 12-20, which is quite similar to the type 8. Components of the type 2 eyebox are somewhat different since attack periscopes do not have a synchro mechanism or antenna waveguide and cables. The type 2 eyebox also has provision for two additional control shafts. (Split lens drive and stadimeter in-out drive.)

Be extremely careful when removing the stuffing box assemblies (47, 59, 95, 107) since they can be withdrawn only from the inside of the eyebox. Do not damage any O-ring seats.

- Disassemble the focusing erector assembly. The exploded view shown in figure 12-21 is common to all periscopes. If there is no damage to the focusing erector assembly, or if lubrication or adjustment is not necessary, you can remove the lenses for cleaning without taking the entire mechanism apart.

- Remove the screw (44) from the housing (46) and raise the lens mount (43) by turning the universal joint (2) until the setscrew (37) is visible through the housing. After loosening the setscrew, remove the lenses in the usual manner.

If complete disassembly is required for any reason, remove the upper and lower bearing plates, retainers, and clamps. Slide the rest of the assembly out the bottom of the housing. Mark all components you remove, if not damaged, so you can replace them in their original positions.

Notice the extensive use of dowel pins in the focusing erector mechanism. The dowels maintain alignment of the three lead screws (35) throughout the full travel of the lens mount (43), which is over 10 inches. If the lead screws were not perfectly parallel with each other, the lens mount would bind, and, if the lead screws were not parallel with the outer housing, the line of sight would not correspond with the mechanical axis of the periscope.

Other alignment problems occur because the multiple lead threads are machined on the lead screws. When the lead screws are inserted into the lead screw nuts (36), you must catch the correct lead so the pinion gears (29) will mesh properly with the drive gear (19). Also, bear in mind that the shoulders on the pinion gears should be equidistant from the face of the drive gear when the unit is assembled.

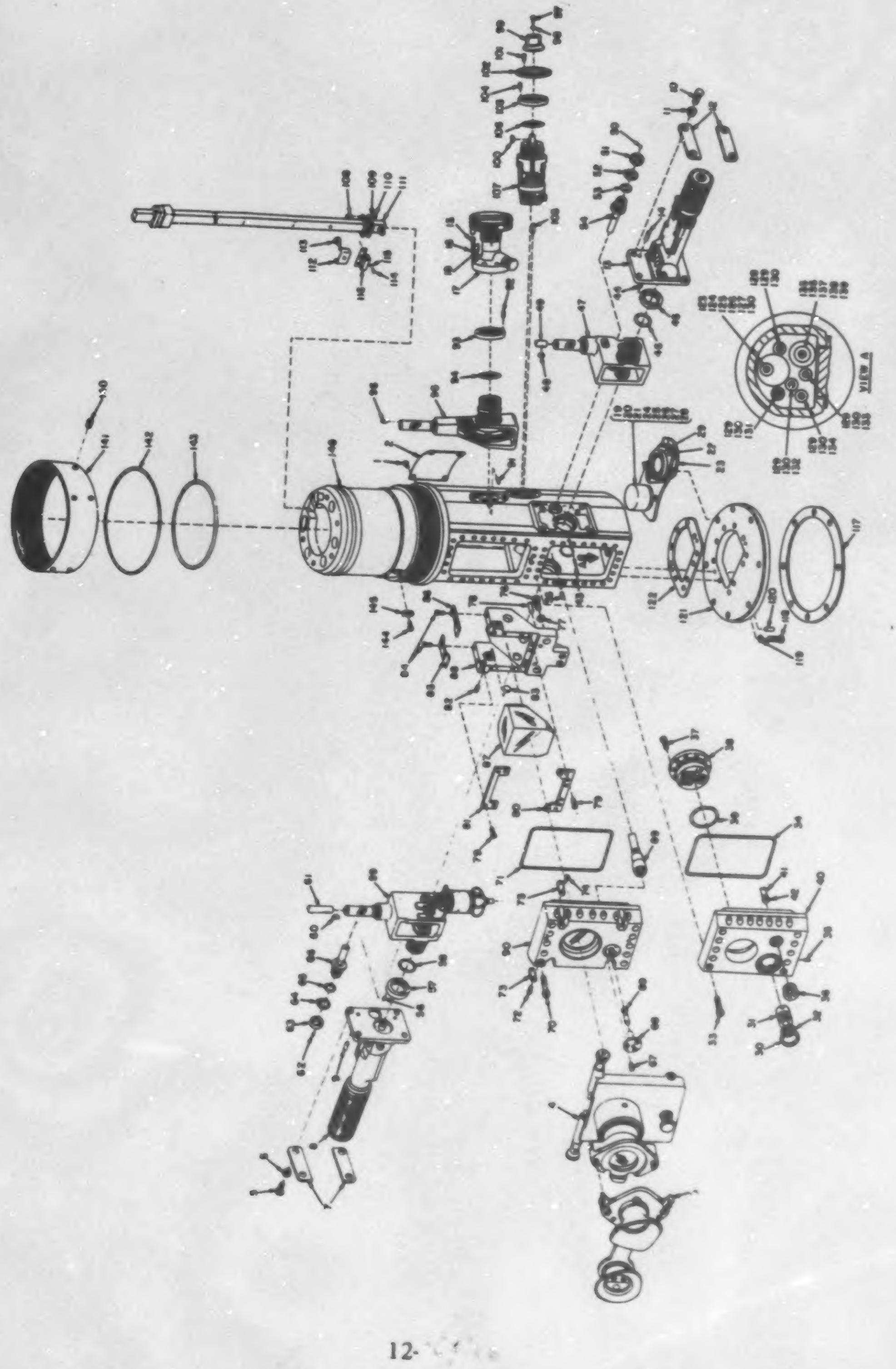
Clamp the stops (33) to one lead screw to limit travel of the lens mount and to prevent the lens mount from being turned off the ends of the lead screws. Set the lower stop about two threads from the end face of the lead screw threads, and clamp the upper stop about 1 inch from the upper end of the lead screw. Final positioning of the upper stop is done during final assembly and collimation.

If you replace any parts in the focusing erector assembly, test the entire unit for binding or excessive play by assembling the unit, using setscrews to secure components. Once you verify proper operation, drill and install dowel or taper pins.

- Disassemble the skeleton head assembly. The skeleton head shown in figure 12-22 is from a type 2 scope. The skeleton heads used on type 8 and 15 periscopes are similar in function but different in detail, and about three times larger.

As you can see in figure 12-22, a periscope skeleton head is somewhat more complicated than the average snap-together model kit. Fortunately, it is seldom necessary to completely disassemble one of these units, except when seawater enters and contaminates the assembly, or when a head prism breaks, spreading fine glass particles through the mechanism. Any opticalman can replace head prisms and Galilean eyelenses or objectives, but only a highly skilled repairman can accomplish a complete disassembly.

All rotating or pivoting elements of the skeleton head are supported by ball bearings

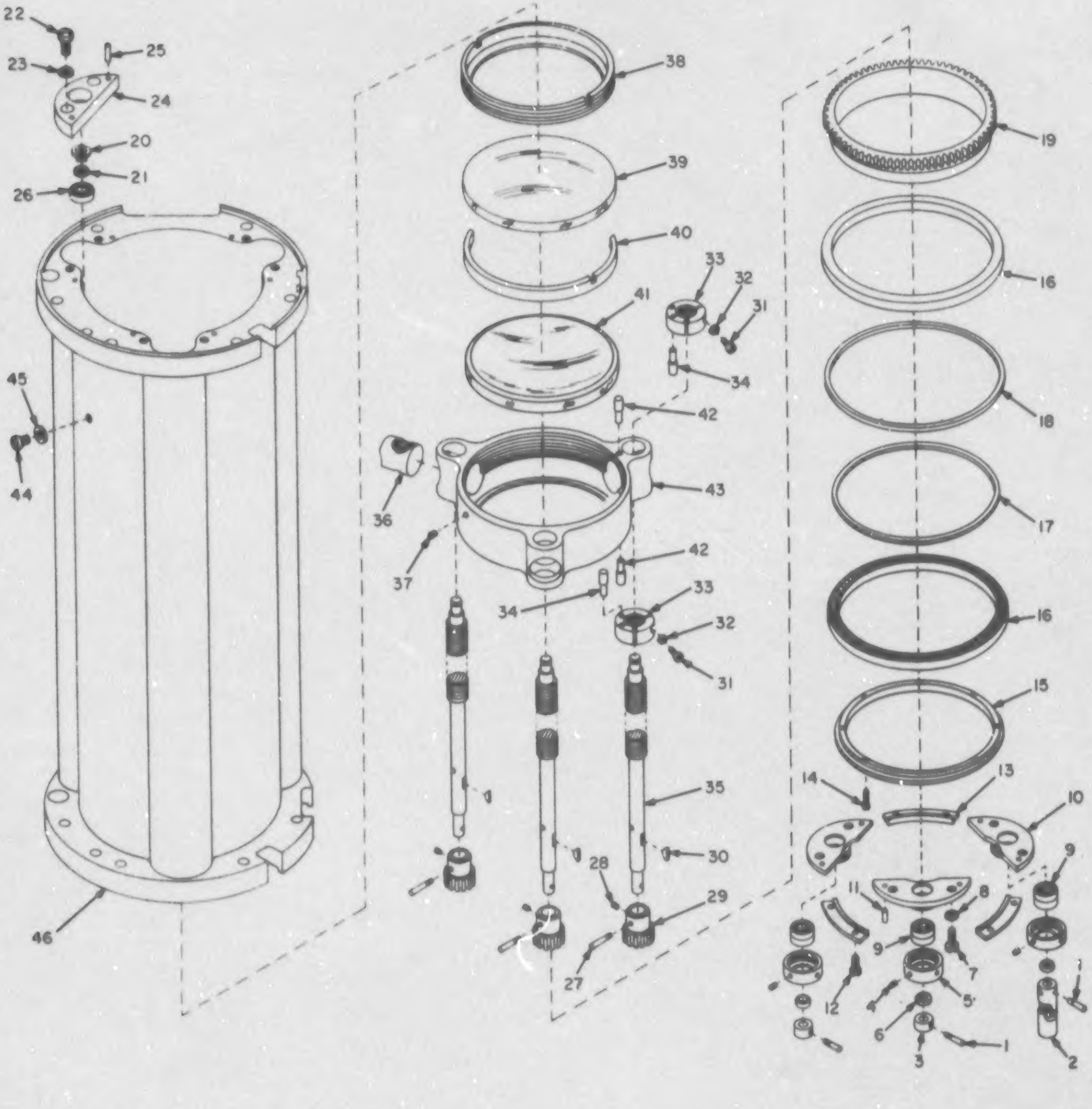

VIEW A

12- [illegible]

1. SCREW, ROUND HEAD
2. NAMEPLATE, PERISCOPE
3. BLINDER ATTACHMENT ASSEMBLY
4. EYEPIECE AND FACEPLATE ASSEMBLY
5. BOLT, HEX HEAD
6. WASHER
7. STOP
8. LEFT TRAINING HANDLE ASSEMBLY
9. PIN, DOWEL
10. BOLT
11. WASHER
12. STOP
13. RIGHT TRAINING HANDLE ASSEMBLY
14. PIN
15. SCREW, CAP
16. WASHER, LOCK
17. FOCUSING KNOB ASSEMBLY
18. PIN, DOWEL
    ACCESSORY PLATE ASSEMBLY with
19. RAY FILTER ASSEMBLY (RED) and
20. RAY FILTER ASSEMBLY (GREEN)
21. RAY FILTER ASSEMBLY (YELLOW)
    RAY FILTER (YELLOW)
    MOUNT, FILTER LENS
    CLAMP RING
22. PIN, ANCHOR
23. PLATE, ACCESSORY MOUNTING
24. MAGAZINE, RAY FILTER
25. PAD
26. COVER, MAGAZINE
27. PAD
28. SCREW
29. VARIABLE FILTER ATTACHMENT ASSEMBLY
30. RETAINER, PLUG
31. PLUG, SEALING
32. O-RING
33. SCREW, SPECIAL
34. O-RING
35. PIN, DOWEL
36. VALVE, GAS INLET
    PLUG, Air vent inlet
    BODY
    SCREW, Air Valve
    BALL, 3/16 CRES
37. SCREW, CAP
38. PRESSURE GAUGE AND VALVE ASSEMBLY
39. O-RING
40. LOWER DOOR
41. HOSE, FLEXIBLE
42. O-RING
43. PIN, DOWEL
44. SETSCREW
45. LOCKRING
46. O-RING
47. RIGHT TRAINING HANDLE STUFFING BOX ASSEMBLY
48. KEY, WOODRUFF
49. POWER CHANGE SHAFT
50. SETSCREW
51. LOCKRING
52. WASHER, LOCK
53. O-RING
54. ELECTRICAL PLUG
55. PIN
56. SETSCREW
57. LOCKRING
58. O-RING
59. LEFT TRAINING HANDLE STUFFING BOX ASSEMBLY
60. KEY
61. ALTISCOPE SHAFT (Lower taper)
62. SETSCREW
63. LOCKRING
64. WASHER
65. O-RING
66. PLUG, EPB
67. SCREW, FLAT HEAD
68. INSULATOR CAP
69. CONTACT SPRING ASSEMBLY
70. SCREW
71. O-RING
72. SCREW, FLAT HEAD
73. CLIP
74. SCREW
75. CLIP
76. SCREW, FILL HEAD
77. WASHER, FLAT
78. PIN, DOWEL
79. SCREW, FLAT HEAD
80. CLAMP
81. CLAMP
82. SETSCREW
83. PAD
84. SCREW, FLAT HEAD
85. CLAMP
86. CLAMP
87. EYEPIECE PRISM
88. EYEPIECE PRISM MOUNT
89. MINIATURE RECEPTACLE
90. STAUNCHING PLATE ASSEMBLY
91. PIN
92. SETSCREW
93. LOCKRING
94. O-RING
95. FOCUSING KNOB STUFFING BOX ASSEMBLY
96. KEY
97. SCREW, FILL. HEAD
98. WASHER, LOCK
99. KNOB
100. KEY, WOODRUFF
101. SCREW, FILL. HEAD
102. PLATE, TELEMETER RHEOSTAT
103. PIN, DOWEL
104. SETSCREW
105. LOCKNUT
106. O-RING
107. TELEMETER RHEOSTAT STUFFING BOX ASSEMBLY
108. SCREW, CAP
109. WASHER, LOCK
110. NUT, HEXAGON
111. ADAPTER, WAVEGUIDE
112. RETAINER COUPLING
113. COUPLING, HOSE
114. SCREW, CAP
115. WASHER, LOCK
116. BRACKET, WAVEGUIDE
117. GASKET
118. SCREW, CAP
119. WASHER, LOCK
120. PIN, DOWEL
121. BOTTOM FLANGE, EYEPIECE BOX
122. GASKET
123. CABLE ASSEMBLY, WAVEGUIDE
    CONNECTOR, CABLE
    CONNECTOR, CABLE
    CABLE, WAVEGUIDE
124. SCREW, FILL. HEAD
125. WASHER, LOCK
126. HOUSING, ADAPTER
127. O-RING
128. LOWER CABLE ASSEMBLY
129. RETAINING WASHER
130. CONNECTOR, PRESSURE TYPE
131. LOWER COMMUNICATIONS CABLE ASSEMBLY
132. LOWER CABLE ASSEMBLY
133. LOWER CABLE ASSEMBLY
134. LOWER CABLE ASSEMBLY
135. EYEPIECE BOX WIRING HARNESS ASSEMBLY
136. SETSCREW
137. RING, RETAINING
138. O-RING
139. PIN, DOWEL
140. SETSCREW
141. LOWER COUPLING
142. O-RING
143. O-RING
144. SCREW
145. KEY
146. EYEPIECE BOX

137.549

Figure 12-20.—Eyepiece box component assembly.



137.560

Figure 12-21.—Focusing erector assembly.

1. TAPER PIN
2. JOINT, UNIVERSAL
3. COLLAR, SHAFT
4. SETSCREW
5. CAP, BEARING
6. SPACER
7. SCREW, FILL. HEAD
8. WASHER, LOCK
9. BEARING, DUPLEX
10. RETAINER, BEARING
11. PIN, DOWEL
12. SCREW, SELF-LOCKING
13. CLAMP, BEARING
14. SCREW, SELF-LOCKING
15. CLAMP, RING
16. BEARING
17. SPACER, BEARING: Inner race
18. SPACER, BEARING: Outer race
19. GEAR, DRIVE
20. RING, RETAINING
21. SPACER
22. SCREW, FILL. HEAD
23. WASHER, LOCK
24. PLATE, BEARING
25. PIN, DOWEL
26. BEARING
27. TAPER PIN
28. SETSCREW
29. GEAR, PINION
30. KEY, WOODRUFF
31. SCREW, ROUND HEAD
32. WASHER, LOCK
33. CLAMP, STOP
34. PIN, STOP
35. LEAD SCREW
36. NUT, LEAD SCREW
37. SETSCREW
38. LOCKRING
39. ERECTOR, CROWN
40. SPACER, LENS
41. ERECTOR, FLINT
42. PIN, STOP
43. MOUNT, LENS
44. SCREW, BIND. HEAD
45. WASHER, LOCK
46. HOUSING, FOCUSING ERECTOR

Legend for figure 12-21.

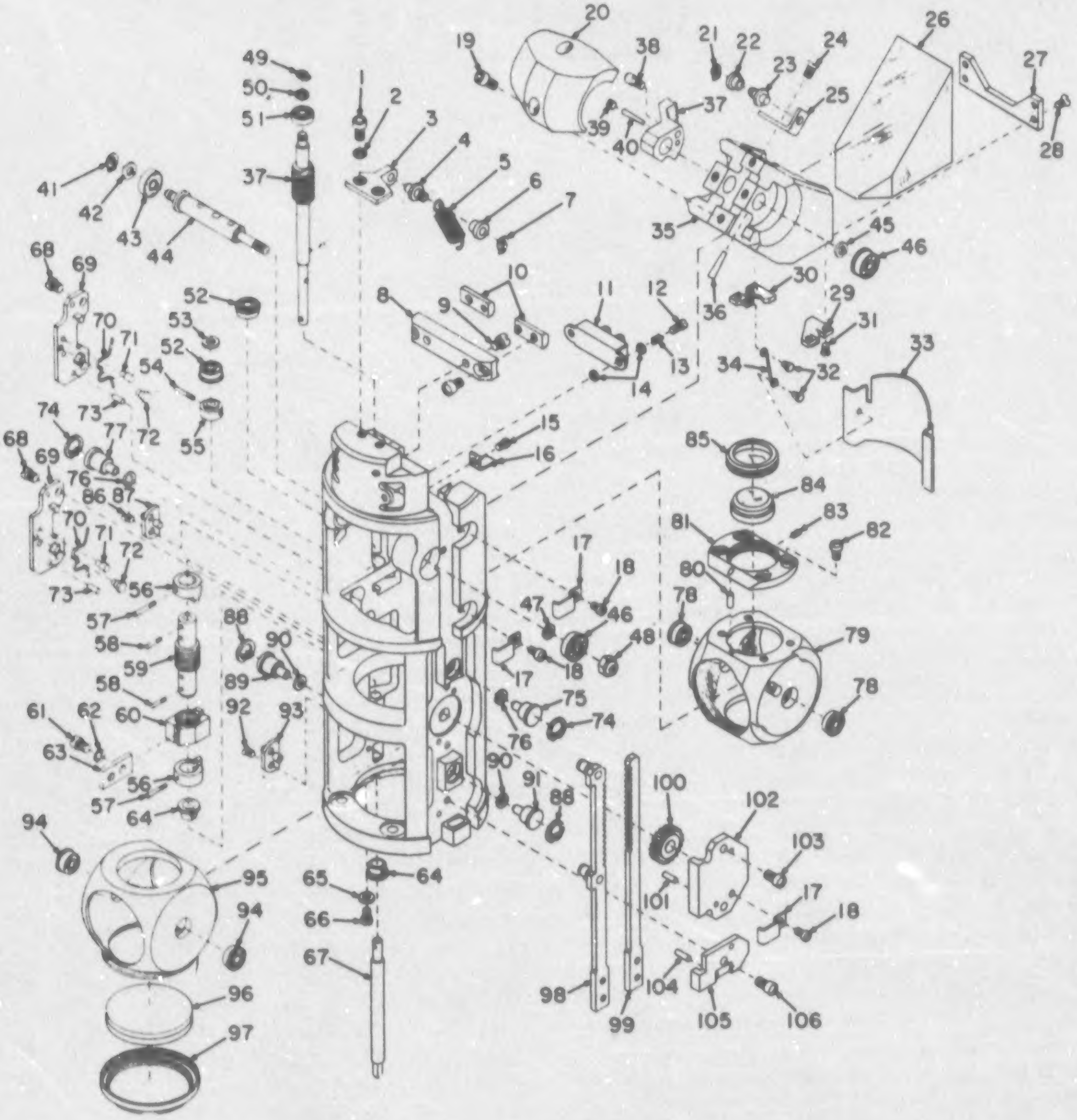
which provide friction free movement. These bearings are either slightly preloaded or machined to zero clearance to eliminate any end play. Cleanliness and proper lubrication of bearings and bearing surfaces are essential to maintain the precision of the skeleton head.

Since the Galilean telescope shifts in and out of the line of sight, the Galilean eyelens cube (79) has several adjustments to align the low-power line of sight with the high-power system. The Galilean eyelens (84) is held in a lens mount (85) which screws in and out of an adjusting nut (81) to provide a parallax adjustment. The screw holes in the adjusting nut (81) are elongated so the adjusting nut can be pivoted left and right around a dowel pin (80) to eliminate displacement of the line of sight when the periscope is shifted from high power to low power. Detent springs (70) hold the two cubes in either the high-power or low-power positions.

The basic elevation mechanism components in the skeleton head consist of a shaft (67), coupling (59), and worm and worm gear assembly (37). Associated bearings, spacers, pins, and retainers can readily be seen in figure 12-22. It is important to note that the worm and worm gear (37) make up a matched set, and must be replaced, if necessary, with another set. The elevation stops in the skeleton head consist of a nut (60), stops (56), and coupling (59). The stops (56) are pinned to a coupling (59) which is free to rotate. Rotation of the coupling drives a nut (60) up or down until it contacts the upper or lower stop. A nut guide (63) engages a slot in the nut to prevent it from rotating. The elevation stops in the type 2 skeleton head are set to provide 1/4° of elevation overtravel at +74° and -10°. To prevent damage to this delicate mechanism, the stops in the left training handle should engage before the stops in the skeleton head.

After reassembling the skeleton heads of type 8 and type 15 periscopes, you must make several other important tests. Since these scopes are used for celestial navigation, the zero elevation position of the head prism must be established, the head synchro must be aligned electrically to read zero elevation, and a backlash test must be run on the elevation mechanism.

These tests and adjustments are necessary so that the navigator of the submarine will know



137.551

Figure 12-22.—Head skeleton assembly.

1. Screw
2. Washer, Lock
3. Bracket, Spring
4. Shaft, Spring
5. Spring, Extension
6. Retainer, Spring
7. Ring, Retaining
8. Insulator
9. Screw
10. Terminal
11. Switch, Thermo
12. Screw
13. Spring, Compression
14. Washer
15. Screw
16. Retainer Wire
17. Retainer Wire
18. Screw
19. Screw
20. Counterweight
21. Ring, Retaining
22. Retainer, Spring
23. Shaft, Spring
24. Screw
25. Bracket, Spring
26. Prism, Head
27. Retainer, Prism
28. Screw
29. Retainer, Prism
30. Retainer, Prism
31. Screw
32. Pin
33. Shade, Sun
34. Wire, Prism Shade
35. Mount, Head Prism
36. Pin, Taper
37. Worm & Worm Gear Assy
38. Screw
39. Screw, Set
40. Pin, Taper
41. Ring, Retaining
42. Spacer, Shim
43. Bearing
44. Shaft, Prism Pivot
45. Spacer
46. Bearing
47. Spacer
48. Locknut
49. Ring, Retaining
50. Spacer, Shim
51. Bearing
52. Bearing, Flanged
53. Spacer
54. Pin, Taper
55. Collar
56. Stop
57. Pin, Taper
58. Pin, Taper
59. Coupling
60. Nut
61. Screw
62. Lockwasher
63. Guide nut
64. Bearing, Flanged Nylon
65. Washer
66. Screw
67. Shaft, Coupling
68. Screw
69. Stop, Cube
70. Spring, Cube
71. Pin
72. Pin
73. Pin, Dowel
74. Ring, Retaining
75. Pin, Cube Pivot
76. Spacer
77. Pin, Cube Pivot
78. Bearings
79. Cube, Galilean Eyepiece
80. Pin, Dowel
81. Nut, Adjusting
82. Screw
83. Screw, Set
84. Eyepiece, Galilean
85. Mount, Lens
86. Screw
87. Pin, Stop
88. Ring, Retaining
89. Pin, Cube Pivot
90. Spacer
91. Pin, Cube Pivot
92. Screw
93. Pin, Stop
94. Bearing
95. Cube, Galilean Objective
96. Objective, Galilean
97. Retainer, Lens
98. Cube Shifting Rack Assy
99. Rack, Cube Shifting
100. Pinion
101. Pin, Dowel
102. Bracket, Pinion
103. Screw
104. Pin, Dowel
105. Retainer, Rack
106. Screw

Legend for figure 12-22.

how much error to expect for any angle of elevation. You will find tables and procedures for conducting the elevation tests and adjustments in the appropriate periscope technical manuals and in NAVSHIPS 0924 001 0000 (Altiscope Angle Comparator).

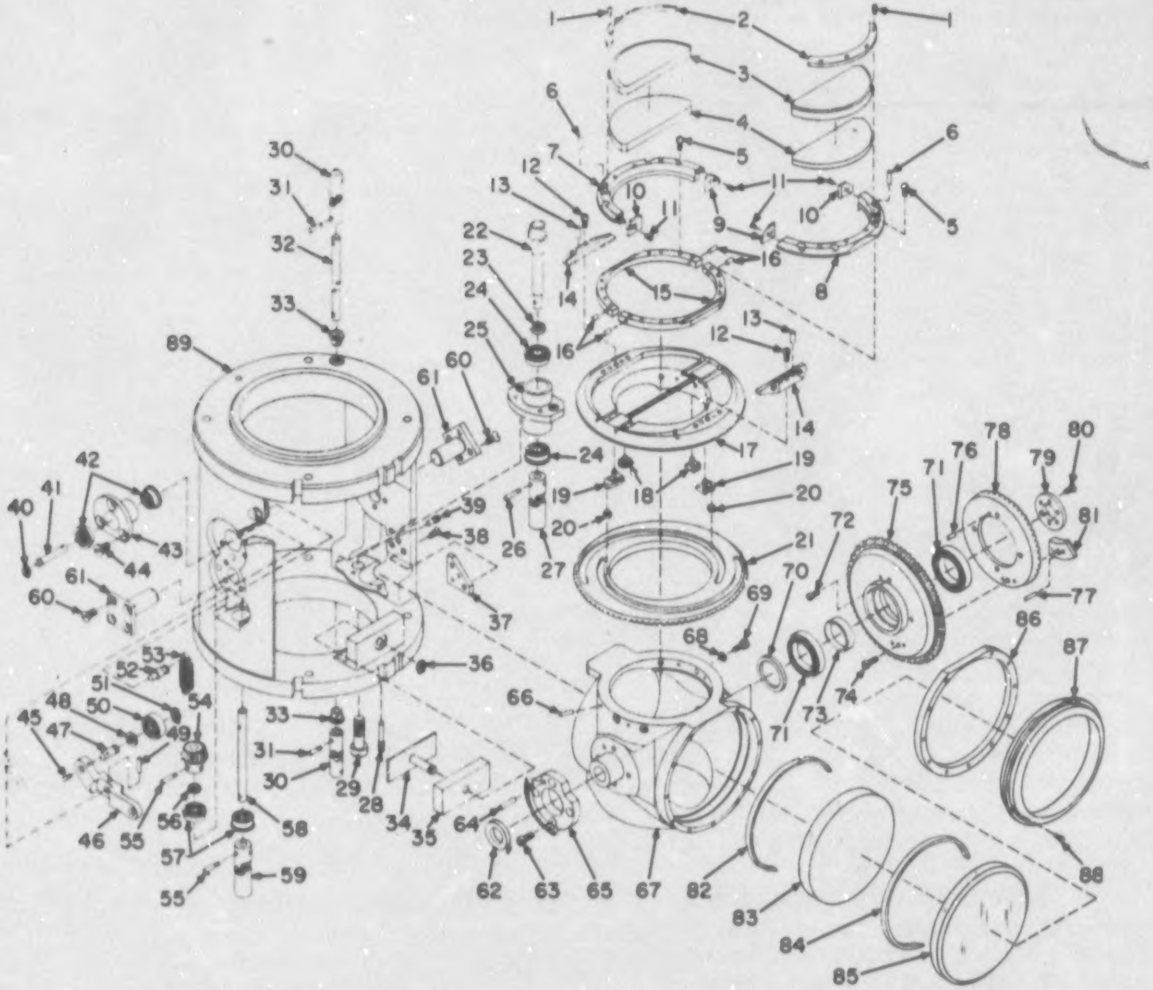
- Disassemble the stadimeter lens mechanism assembly. Remember, the stadimeter assembly (fig. 12-23) is found only on type 2 periscopes. The precision of machining and fit which was necessary in the skeleton head also applies to this mechanism. Mark all the parts you remove as an aid to reassembly.

Several problems of mechanical and optical alignment are unique to this assembly. First of all, bevel gears are used to operate the split lens and to shift from split lens to solid erector. Meshing of these gears must be perfect to eliminate backlash. Secondly, when the cube is shifted from solid to split lens and vice versa, displacement of the line of sight must not exceed ±5 minutes of arc. Thirdly, the split lens and solid erector must be parfocalized (focal lengths of the lenses must be equal) within ±0.5 mm of focal length. Since the split lens is more expensive and more complex, adjustment is made by machining spacers in the solid erector or by replacing both solid erector elements. Finally, and most difficult, when the cam gear (21) is turned to operate the split lens, a rotation of a set number of degrees must result in a rigidly specified movement of the two split lenses. The tolerance allowed for this movement must be within ±0.0003 inch.

There is nothing simple about any work performed on the stadimeter lens mechanism assembly. You will need a high degree of skill and patience to disassemble, repair, reassemble, and adjust this unit. You must strictly adhere to the step by step procedure outlined in NAVSHIPS 324-0487.

Cleaning

Some cleaning of optics and mechanical components, such as skeleton head, 6th erector, eyepiece box, and split lens, is done during the repair and reassembly phase of overhauling individual periscope assemblies. It is absolutely essential that all possible forms of



137.552

Figure 12-23.—Stadimeter lens mechanism assembly.

contamination be eliminated in preparing a periscope for reassembly. Lubrication must be applied sparingly; mechanical assemblies should slide together smoothly to avoid formation of metal shavings. Inner tube sections must be thoroughly cleaned to remove particles which could fall on optics.

During disassembly, when lens mounts were removed, the open ends of inner tube sections were covered with masking tape. To clean the insides of these sections, suspend them from wire on a nylon line in the same position they would be in an assembled scope. Tap the outer surface of the suspended inner tube sections with a fiber mallet, working from the top down, to dislodge trapped particles. The loosened contamination is trapped on the masking tape.

Remove the masking tape, apply fresh tape, and repeat the tapping until no more contamination can be seen on the tape. Retape

1. Screw
2. Cover, Lens Mount
3. Erector, Split, Flint
4. Erector, Split Crown
5. Screw
6. Pin, Dowel
7. Mount, Lens
8. Mount, Lens
9. Clip, Lens
10. Clip, Lens
11. Screw
12. Screw
13. Pin, Dowel
14. Rail
15. Support, Mount
16. Pin, Taper
17. Retainer, Cam
18. Guide, Mount
19. Follower, Cam
20. Shoe
21. Gear, Cam
22. Pinion, Bevel
23. Spacer, Pinion
24. Bearing, Flanged
25. Bracket, Pinion
26. Pin, Taper
27. Joint, Universal
28. Dowel, Locating
29. Screw
30. Joint, Universal
31. Pin, Taper
32. Shaft
33. Bearing, Flanged
34. Plate, Bumper
35. Stop
36. Ring, Retaining
37. Plate, Stop
38. Screw
39. Pin, Dowel
40. Ring, Retaining
41. Shaft
42. Bearing
43. Adapter
44. Screw
45. Pin, Taper
46. Bracket, Detent
47. Stud, Roller
48. Spacer
49. Pin, Taper
50. Bearing
51. Ring, Retaining
52. Pin, Spring
53. Spring, Extension
54. Pinion, Detent
55. Pin, Taper
56. Spacer
57. Bearing, Flanged
58. Shaft
59. Joint, Universal
60. Screw
61. Pivot
62. Washer
63. Screw
64. Pin, Dowel
65. Gear, Detent
66. Pin, Dowel
67. Mount, Stad.
68. Washer, Lock
69. Screw
70. Spacer
71. Bearing
72. Screw
73. Spacer, Bearing
74. Screw
75. Gear, Driving
76. Pin, Dowel
77. Pin, Dowel
78. Gear, Bevel
79. Retainer, Bearing
80. Screw
81. Stop
82. Spacer, Lens
83. Erector, Crown
84. Spacer
85. Erector, Flint
86. Spacer, Lens Cover
87. Cover, Lens
88. Screw
89. Skeleton, Stadimeter

Legend for figure 12-23.

the tube sections until you are ready to install the lens mounts.

The procedure for cleaning lenses was covered in Chapter 7 of this manual. Cleaning periscope optics presents several other problems.

- The erectors are quite large and acetone will leave streaks if you are not careful.

- Since the optics are stacked up, any dirt in the tube sections will fall on the lenses and be visible.

- Due to the travel of the focusing erector, the surface of all lenses in the scope can be seen at various times when the erector is being cranked from normal viewing position to camera position.

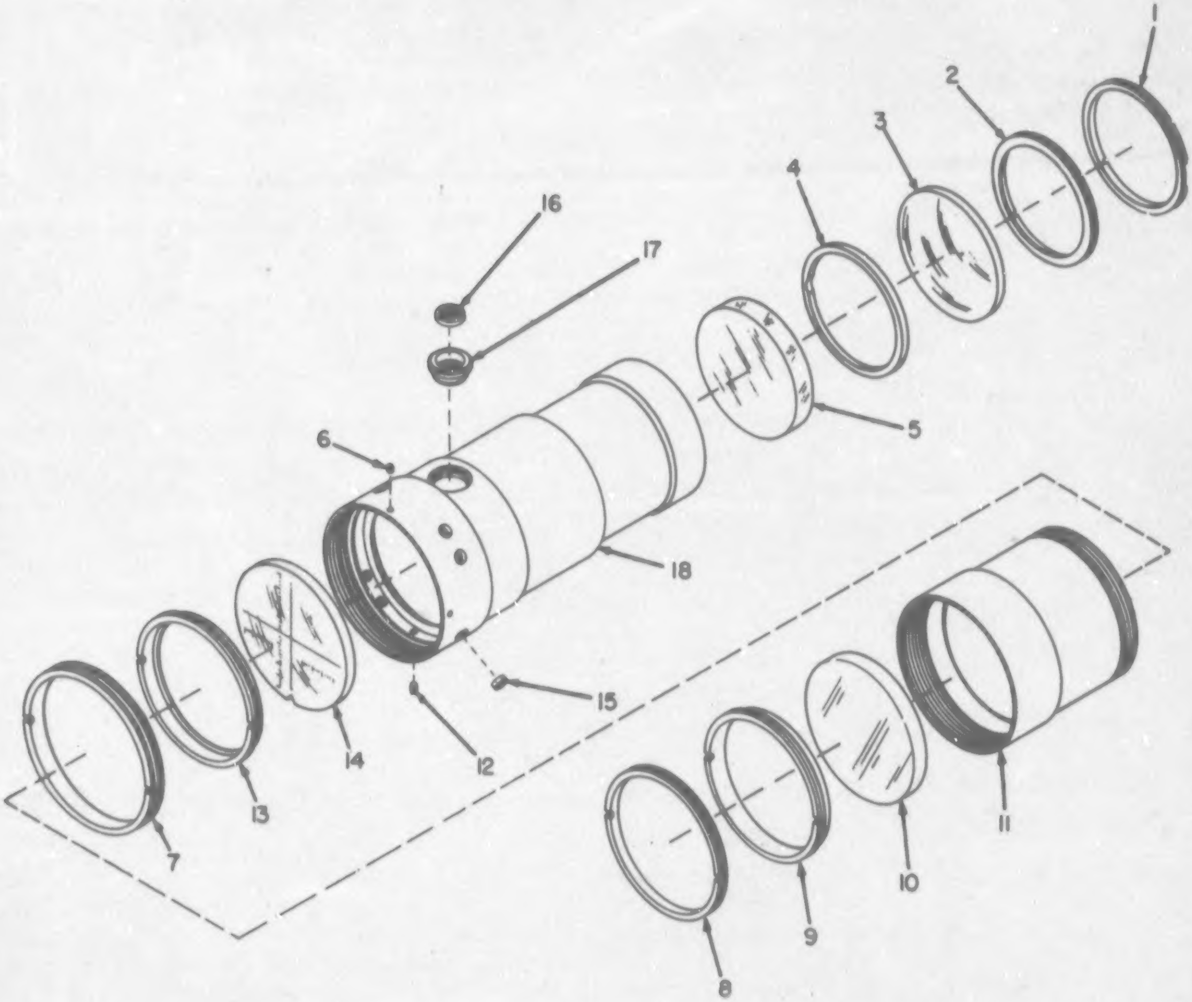
- The telemeter must be super spotless—no scratches, no streaks, no lint—absolute cleanliness is the minimum requirement. Even in the clean room, it can take anywhere from 15 minutes to a whole day to satisfactorily clean the telemeter.

The telemeter lens mount for a type 15 periscope is shown in figure 12-24. This arrangement is similar to that used on the type 2 and 8 scopes. Parts 3 and 5 are the two elements of the field flattener. They are located in the telemeter lens mount. A sealing window (10) is found only on type 15 periscopes.

The telemeter lens mount must be scrupulously clean if you hope to end up with a clean telemeter when the scope is assembled. Part 16 in figure 12-24 is a fine mesh air filter. Since nitrogen must be free to circulate around all optics in the scope, the filter allows circulation but prevents entry of dust or lint.

Reassembly and Collimation

A submarine periscope has many separate collimation requirements, including the common requirements, such as parallax, 0-diopters, squareness of the telemeter, and elevation of the



1. LOCK RING, FIELD LENS
2. RETAINER, FIELD LENS
3. FLATTENER, FIELD
4. SPACER, FIELD LENS
5. FLATTENER, FIELD
6. SETSCREW
7. RETAINER, TELEMETER LENS MOUNT
8. LOCKRING, TELEMETER LENS
9. RETAINER, SEALING PLATE
10. SEALING PLATE, TELEMETER
11. MOUNT, SEALING PLATE
12. SETSCREW
13. RETAINER, TELEMETER LENS
14. TELEMETER LENS
15. FILTER, RED
16. FILTER, AIR
17. MOUNT, AIR FILTER
18. MOUNT, TELEMETER LENS

137.553

Figure 12-24.—Telemeter lens mount assembly.

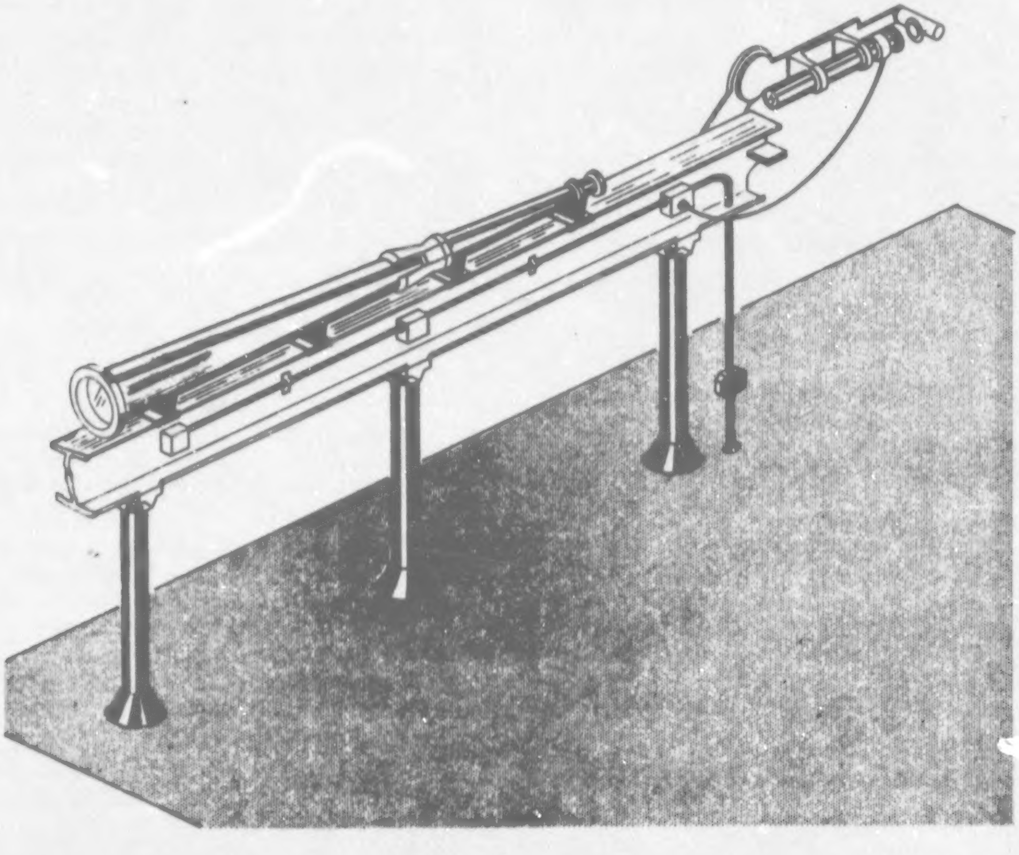
line of sight. It also has a few uncommon collimation requirements, such as nitrogen compensation, relay system collimation, stadimeter collimation, and displacement. Collimation of various subassemblies is done during and in conjunction with reassembly.

The submarine periscope collimator is designed to reproduce the various collimation distances–optically. Place the collimator target in a threaded tube so you can move the target in relation to the collimator objective. A scale engraved on the collimator body shows the various available distances. Use the distances shown below in collimating the various periscopes in air to compensate for the introduction of nitrogen.

Periscope	Distance (feet) (HP)	 (LP)
2D, 2E, 2F	3,171	49
8B, 8C, 15B, 15D	3,171	52

Keep in mind that these distances shown apply only to the assembled periscope, the procedure for collimating subassemblies will follow.

FIRST ERECTOR AND HIGH POWER OBJECTIVE.–With the high power objective, field flattener, telemeter, and first erector installed in the first and second inner taper tubes, place the tubes on the periscope rail in line with the periscope collimator, as shown in figure 12-25. With an auxiliary telescope set to



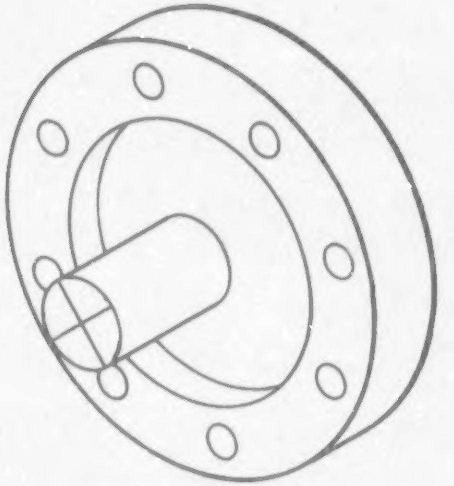
148.358

Figure 12-25.–Primary collimation.

your eye, move the first erector until the telemeter appears sharply defined. Set the periscope collimator to the prescribed distance for high power collimation of the particular type of periscope you are working on. Adjust the high power objective so that images of the collimator reticle and telemeter appear in the same plane (no parallax). NOTE: For proper magnification of the high power system (and optimum accuracy of the ranging mechanism), the focal lengths of the first and second erectors must not differ more than 1% (12 mm), and the focal length of the third and fourth erectors must not differ more than 1% (12 mm).

To provide the correct image plane references for collimating in air, use a special crosswire fixture similar to that shown in figure 12-26. Specifications for making these fixtures for different periscopes are in the appropriate periscope technical manual.

SECOND ERECTOR.—Replace the first collector lens mount with the appropriate crosswire fixture. With the second erector installed, reconnect the first and second inner tubes. Sighting through the second erector with an auxiliary telescope, move the erector to remove parallax between the collimator telescope reticle (set at infinity) and the crosswire.



148.359

Figure 12-26.—Typical crosswire fixture.

THIRD ERECTOR.—Install the third erector in the lower end of the third inner tube and the appropriate crosswire fixture in the upper end of the third inner tube. Sighting through the third erector with the auxiliary, move the erector to remove parallax (collimator set at infinity).

FOURTH ERECTOR.—Install the fourth erector in the lower end of the fourth inner tube. Install the appropriate crosswire fixture in the lower end of inner tube No. 5. Sight through the fourth erector and remove parallax (collimator set at infinity).

FIFTH ERECTOR.—Install the appropriate crosswire fixture into the top of the sixth inner tube. Place the tube and the stadimeter lens mechanism assembly on the periscope rail so that the fifth erector is adjacent to the lower end of the sixth inner tube. Sighting through the fifth erector, with the collimator set at infinity, remove parallax on the crosswire by shifting the entire split lens mechanism closer to or farther from the lower end of the sixth inner tube. When parallax is removed, accurately measure the distance between the flanges of inner tube No. 6 and the stadimeter lens assembly.

STADIMETER SPLIT LENS.—The fifth erector and the stadimeter split lens must be parfocalized (have their focal planes at the same point) to the point established by the crosswire fixture at the upper end of the sixth inner tube. Use the same setup as for the fifth erector, except that the split lens is in the line of sight. Remove parallax again by shifting the stadimeter lens mechanism back and forth. Measure the distance between the flanges. It should correspond, within ±0.5 mm, to the distance measured for the fifth erector. If it does not, shift the fifth erector in its mount until the measurements correspond. These measurements determine the size of the spacer between the flanges of the sixth inner tube and the stadimeter lens mechanism. NOTE: The foregoing procedure for the 5th erector/split lens applies only to type 2 periscopes. The fifth erector on type 8 and 15 periscopes is collimated like the upper erectors.

When each of the erectors is collimated, remove the crosswire fixtures and seal the open ends of the tube sections with masking tape. Set the sections aside until ready for final assembly.

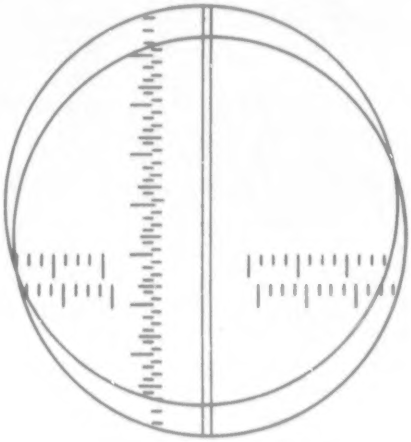
CORRECT DIOPTER SETTING.–Assemble the focusing erector assembly, lower taper tube, eyepiece box, and eyepiece on the periscope rail and focus sharply on the collimator (at infinity), using an auxiliary telescope. This is the 0-diopter setting in air and must be adjusted for 0-diopters when the periscope is charged with nitrogen. Make the adjustment by moving the 6th erector a specified distance toward the collimator. The distance will vary with each type of periscope. Now, set the upper stop of the focusing erector assembly to allow +1.65 diopters focus travel when the periscope is charged. Adjust the stop as specified in the appropriate technical manual. Check the lower stop position also at this time. Adjust the focus knob, if necessary, to read 0-diopters.

SQUARE THE TELEMETER AND CHECK TRAVEL OF THE HEAD PRISM.–On type 2 periscopes, assemble all tube sections from the split lens mechanism through the eyebox. You now have to align the split lens to the eyebox. Place a leveled transit at the end of the periscope rail so you can sight the split lens. Place a machinist's square on the eyebox staunching plate (90 in fig. 12-20). With the transit, sight the vertical edge of the square and rotate the eyebox to align the square with the transit crossline. Now, swing the transit down and focus on the split lens. If the split lens is not perfectly aligned with the transit crossline, rotate the split lens mechanism or inner tube sections to obtain alignment. NOTE: Do not disturb the position of the eyebox.

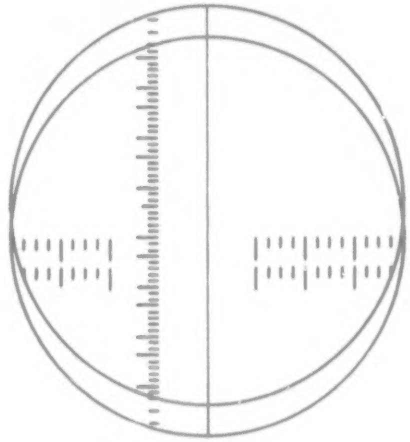
When you have aligned the split lens with the eyebox, secure all tube sections and install dowel pins.

On all types of periscopes, after you have collimated the individual erectors, assemble the remaining inner tube sections, replace the shafting, install the skeleton head, replace the power shift tapes, and install the handles. NOTE: If new tapes are used, they must be prestressed as specified in the appropriate technical manual to prevent unwanted stretching while in service.

When squaring the telemeter of a type 2 periscope, operate the split lens mechanism to open the split lens. If the telemeter is not squared, you will have duplication of the vertical line of the telemeter, as seen in figure 12-27A. Loosen the screws which secure the telemeter



A. DUPLICATION OF VERTICAL CROSSLINE



B. NO DUPLICATION

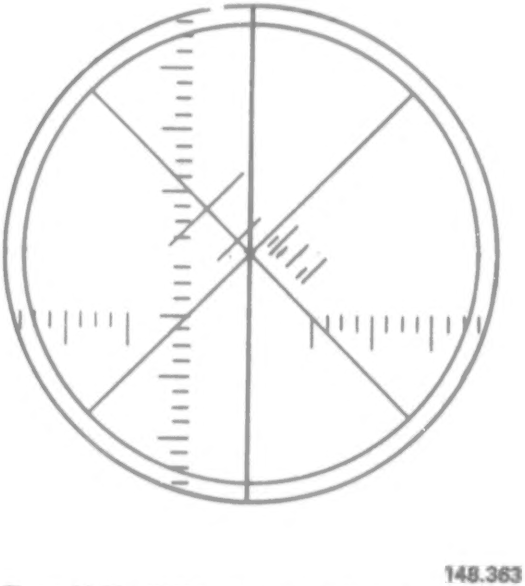
148.367

Figure 12-27.–Duplication check.

mount and rotate the telemeter mount until duplication is eliminated (fig. 12-27B). Secure the telemeter and return the split lens to its original position.

To check the travel of the head prism, set the collimator to the HP distance discussed in the section on reassembly and collimation and align the collimator with the skeleton head. (Be sure the periscope is set in high power.) Now rotate the collimator 45° and align the intersection of the collimator crosslines with the telemeter vertical line as shown in figure 12-28. By elevating and depressing the line of sight to the extreme edges of the collimator field, check to see that the intersection of the collimator target remains perfectly aligned with the telemeter vertical line. If the collimator target appears to track to either side of the telemeter vertical line at opposite edges of the field, the rotational axis of the head prism is not properly oriented. NOTE: Make this check with an auxiliary telescope to magnify the telemeter and collimator images so you can more accurately determine if a possible error can be made.

If you do not have perfect tracking of the line of sight, reposition the skeleton head and/or inner tube sections above the telemeter by removing dowel pins and loosening the securing bolts between sections. After rotating the skeleton head slightly, recheck the tracking of the line of sight. Continue to reposition the skeleton head and check tracking until perfect coincidence of the collimator and telemeter is evident through the full visible travel of the line of sight. NOTE: If you cannot obtain the necessary coincidence by rotating components above the telemeter, loosen one or more joints below the telemeter. If you must loosen the joints, you will need to square the telemeter to the split lens again before you check tracking of the line of sight.



148.363

Figure 12-28.—Collimator in rotated position (HP).

After obtaining proper tracking of the line of sight, secure all tube sections and replace the dowel pins.

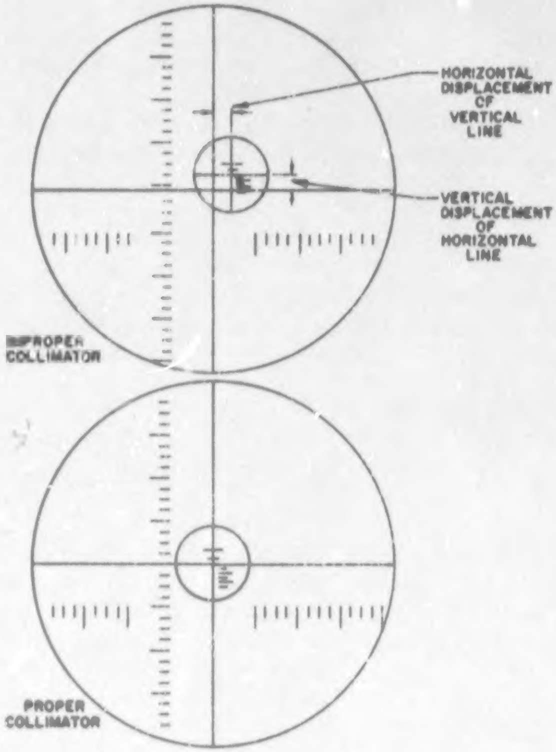
For type 8 and type 15 periscopes, set a leveled transit below the eyebox in line with the axis of the periscope. Set a machinist's square on the eyebox staunching plate and rotate the periscope until the edge of the square is aligned with the transit crossline. Now shift the line of sight and focus on the edge of the head prism. If the prism edge aligns with the transit crossline, there is no problem. If perfect alignment is not apparent, proceed with repositioning the skeleton head as was done in the type 2 periscope.

After you have properly oriented the head prism to the staunching plate, square the telemeter to the travel of the head prism by observing the tracking of the collimator target on the telemeter vertical line. If perfect tracking is not evident, simply rotate the telemeter mount and recheck. When the collimator crossline remains perfectly superimposed on the telemeter vertical wire, secure the telemeter.

ELEVATION OF THE LINE OF SIGHT.—Before making the check, align (boresight) the collimator so that its line of sight coincides with the periscope's and square the collimator target to the telemeter.

The elevation/depression check may not be accurate if the collimator is not aligned because the pivot point of the head prism may not be the same as the pivot point of the collimator. Since the collimator pivot is an eccentric, it can be adjusted to the same height above the periscope collimation rail as that of the head prism pivot shaft. See figure 12-25. Once the pivot points coincide, make the elevation and depression tests.

Swing the collimator to the proper amount of elevation for your periscope (60° for 8 and 15; 74° for 2). The periscope must elevate so that the horizontal crossline touches the intersection of the collimator crosslines. Depress the collimator to -10°. The periscope must be able to depress to -10°. If the periscope will not elevate or depress as required, adjust the corresponding stop. Also adjust the left training handle at this time so the handle graduations correspond with the line of sight.


HORIZONTAL DISPLACEMENT OF VERTICAL LINE
VERTICAL DISPLACEMENT OF HORIZONTAL LINE
IMPROPER COLLIMATOR
PROPER COLLIMATOR

148.361

Figure 12-29.—Displacement check.

LOW POWER PARALLAX.—Parallax will be introduced when the Galilean telescope is shifted into the line of sight if the Galilean eyepiece lens mount is not properly adjusted. To remove parallax in the low power system, first adjust the periscope collimator to the distance specified for the periscope. Loosen the Galilean eyelens setscrew and screw the eyepiece in or out of the mount, as required, to remove parallax. There is no tolerance for parallax; remove any that is detectable. NOTE: Use an auxiliary telescope.

VERTICAL AND HORIZONTAL DISPLACEMENT OF THE CROSSLINE.—The line of sight of the Galilean telescope must coincide with the line of sight of the rest of the periscope. If not, the position of the image will change when the periscope is shifted from high to low power or vice versa. The result is an error in azimuth or bearing when you change from one power to the other.

To check for displacement, superimpose the reticle (with the periscope in high power) on the crossline of the collimator. Now shift the periscope into low power and set the collimator to the low power position for the periscope you are working on. Figure 12-29 shows correct and incorrect collimation for displacement. Horizontal or vertical displacement, or both, may appear in any quadrant of the reticle. NOTE: The telemeter of type 2 periscopes does not have a horizontal line as do type 8 and type 15 telemeters. Compare figure 12-27 and 12-29.

To remove horizontal or vertical displacement, loosen the screws securing the Galilean eyepiece mount and shift the Galilean eyepiece laterally and/or vertically to place its line of sight in coincidence with that of the high power system. The maximum allowable error for displacement is two minutes' horizontal displacement of the vertical crossline and ten minutes' vertical displacement of the horizontal crossline. There is no reason for you not to eliminate all displacement.

Adjust the right training handle so the detent and index marks are properly placed. The tape tension adjustment (figure 12-19) can be of benefit in adjusting the handle.

Stadimeter Collimation

During reassembly of the split lens mechanism, you tested the assembly for proper travel and backlash. Now, with the periscope inner tubes assembled, eliminate any displacement evident after shifting from the solid 5th erector to the split lens, and make a range check.

Replace the stadimeter on the bottom of the eyebox and test the in-out drive and the range knob. Set the collimator and periscope in high power and see if there is any displacement in shifting the split lens in or out. Remove displacement by filing or building up the cube detent (65 in fig. 12-23).

Prior to making a range check, remove any duplication of horizontal or vertical lines on the telemeter. Simply cover the collimator with several sheets of lens tissue to block the collimator target, and yet have illumination. NOTE: Move one split lens half at right angles to the split, which will adjust duplication of vertical lines. Move the other parallel to the split which will adjust duplication of horizontal lines.

There are two methods to check the ranging accuracy of the stadimeter. One is to operate the split lens to obtain coincidence of successive marks on the telemeter vertical ladder. (See fig. 12-30.) The other is to obtain coincidence of successive marks on the collimator target. (See fig. 12-31.) In the first method, set the height scale on the stadimeter dial for 100 feet. Using the second method, set the height scale at 20 feet to obtain range readings. NOTE: All range checks are made with the periscope in high power.

Overlap of the collimator target, the second method, is the preferred method for making a range check. As you can see by comparing the ranges in figures 12-30 and 12-31, the collimator ranges cover a much wider available area, with a resulting increase in expected accuracy.

Accuracy of overlap ranges must be within ±2% at each step in the check. If for any reason ranges do not check out correctly or if duplication cannot be removed, you may need to repeat the overhaul procedure for the split lens mechanism.

Final Assembly

When all collimation requirements have been met, secure the wiring harnesses and, in the type 8 and type 15, the waveguide and antenna cables. Also, make a final check of all tube section joint fasteners, shafting universal joints, and all screws visible on the inner tube.

Insert the inner tube in the outer tube with the eyepiece facing down and the head prism facing up with the scope in low power, zero elevation. The inner tube must be perfectly aligned with the outer tube and evenly supported to prevent sagging. As you carefully insert the inner tube in the outer tube, wipe all inner tube sections and flanges with acetone and a lint-free cloth.

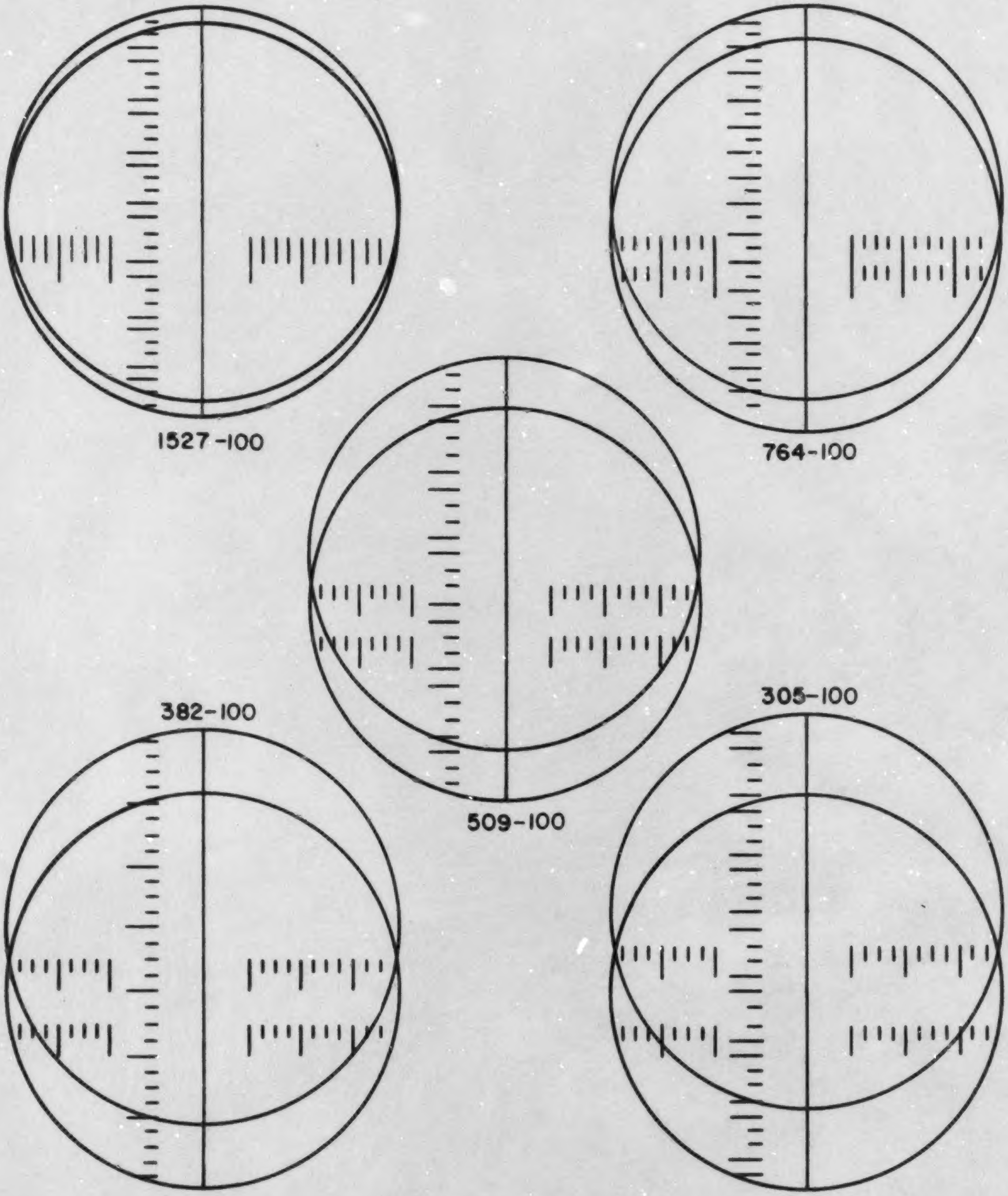
Take particular care with the last foot of inner tube as it enters the outer tube. The O-rings which seal the scope are in this area; the threads of the main coupling must not be damaged; and the inner tube key must remain aligned with the outer tube keyway.

As the inner and outer tubes come together, rotate the main coupling by hand counterclockwise until you feel two jumps. This indicates the starting leads of the threads. One person now pushes the bottom of the eyebox and maintains alignment between the inner and outer tubes, while another tightens the main coupling.

When you have rotated the coupling two or three times, measure the distance between the coupling and tubes—the distances should be within 1/16 inch. If the measurement is not correct, you did not catch the eyebox or outer tube threads at the same time the main coupling was started. When the coupling engagement is correct, tighten the coupling with the special spanner and slug it tight with a mallet.

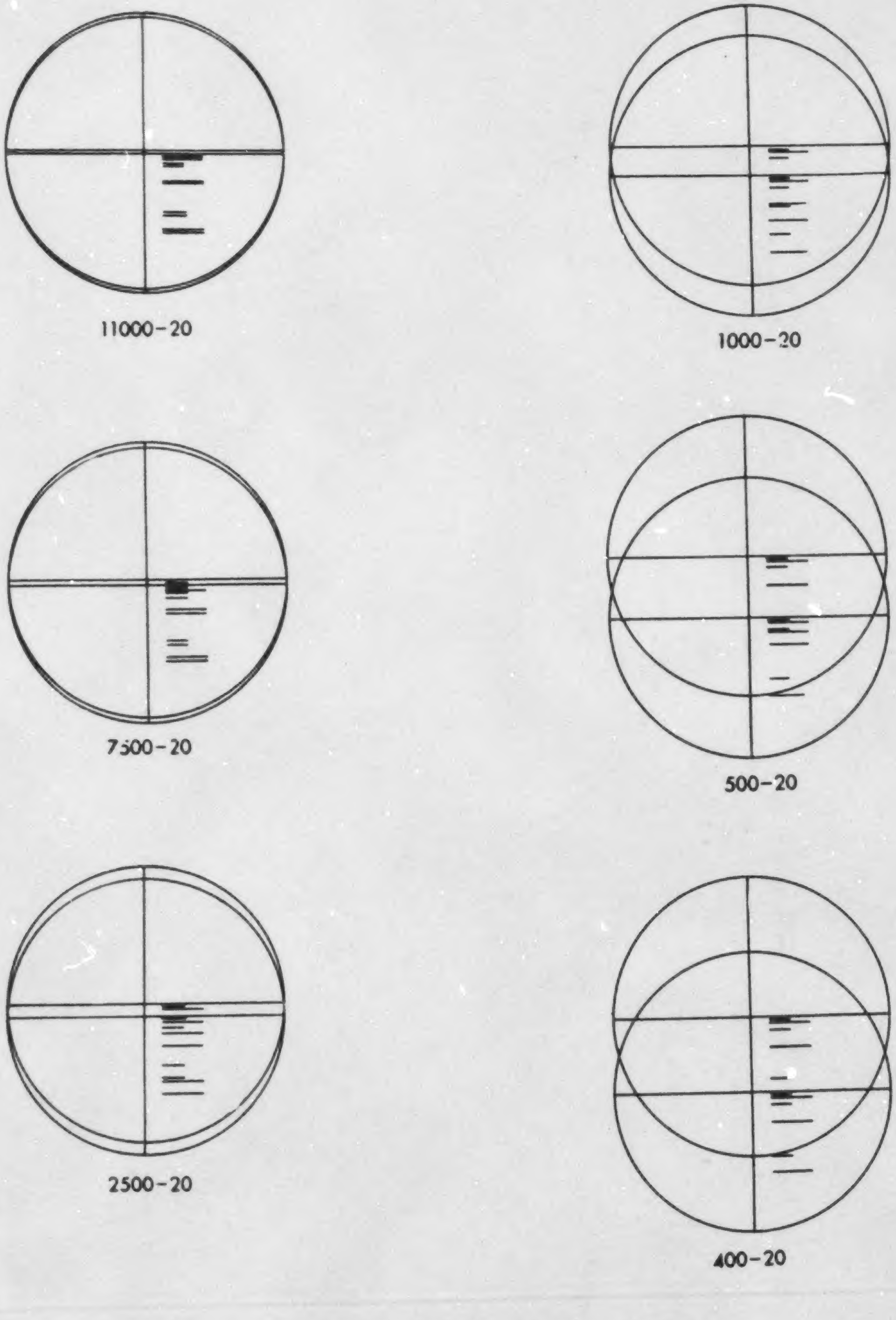
The final step in periscope assembly and collimation is to establish a true optical zero elevation. In the type 8 and type 15 periscopes, the head synchro was electrically aligned with the mechanical zero of the head prism, but no such check is made on the type 2 scopes. Also, due to the thickness and mounting angle of periscope head windows, some optical displacement will be present and must be compensated for.

It is especially important to set the true optical zero position on type 8 and type 15 periscopes since they are used for navigation. A fine synchro (36X) on the skeleton head and a coarse synchro (2X) in the eyebox are connected to the elevation shafts and gears so that they transmit continuous electrical



148.365

Figure 12-30.—Telemeter range references.



11000-20

1000-20

7500-20

500-20

2500-20

400-20

148.366

Figure 12-31.—Collimator range references.

elevation information to a remote recorder. After true optical zero is found, the electrical signal is adjusted to read zero elevation in the recorder.

To find optical zero, mount either two transits or two Mk 8 collimator telescopes (with eyepieces) at right angles to the periscope facing each other. Adjust the transits or collimators to align the crossline of one instrument with the crossline of the opposite instrument. Check back and forth between both instruments until perfect coincidence is established.

Position the periscope so you can superimpose the telemeter on the crossline of one alignment instrument.

Roll the periscope and sight the crossline of the opposite instrument. Note the amount of displacement and direction of displacement from the first sighting. NOTE: You should be concerned only with displacement between the horizontal line of the telemeter and the vertical line of the alignment instrument crossline.

To correct displacement, remove half the error with the scope elevation handle, then align the test instrument with the telemeter. Now adjust the opposite test instrument to the first instrument. Superimpose the telemeter on one test instrument and roll the scope again.

Continue checking one test instrument then the other, making adjustments as necessary, until perfect coincidence of the horizontal lines is established.

The electrical output signal of the synchros can now be read and recorded so the final zero elevation information can be corrected after the periscope is installed.

For type 2 periscopes, once zero elevation is established, adjust the zero elevation detent in the left training handle.

Periscope Cycling

The final step in periscope overhaul is to pressure test the instrument and check for leaks, pull a high vacuum on the scope to remove any moisture present, and then charge the instrument with dry nitrogen. This entire process is called "cycling." Any periscope that exhibits internal fogging, when no other problems are present, is also cycled in the same manner.

It would be difficult to say that any one step in periscope repair is more important than any other. However, if a scope leaks or fogs up in service, it is useless.

During the overhaul procedure, all sealing surfaces were carefully inspected and any O-rings on removed components were replaced. When these steps have been taken carefully and conscientiously, the possibility of gas leakage or entry of seawater is greatly reduced.

PRESSURE TESTING.–We discussed procedures and precautions concerning the use of nitrogen bottles and charging equipment in Chapter 8 of this manual. Now, we will explain pressure testing methods peculiar to periscopes.

- Purge the charging hose before you attach it to the air inlet fitting.

- Attach a pressure gage to the periscope to check internal pressure (0 to 100 psi).

- Set the regulator to 0 (no flow of nitrogen) and attach the charging hose.

- Open the air inlet valve and the nitrogen bottle valve and set the flowmeter for approximately 3 to 5 cubic feet per minute flow rate. If a flowmeter is not available, increase the regulator pressure in 4 psi steps every 5 minutes. It will usually take about 1 hour to build pressure in the periscope to the maximum test pressure of 50 psi.

NOTE: NEVER allow a surge of pressure to enter the periscope. Any rapid increase could damage the scope and will stir up dust or other undesirable particles. Be sure you secure the eyebox pressure gage before internal pressure reaches 30 psi.

- As pressure is building in the scope, check all joints, packing glands, and windows with a soap solution and soft brush. Very carefully observe each possible area of leakage for small bubbles. When using soap for detecting leaks, check the scope at least four times during pressure buildup, since a leak could be evident at 15 psi but not at 45 psi. Make sure the bottle is secured when internal pressure reaches 50 psi.

NOTE: The preferred method for detecting leaks is to submerge the periscope in a tank of water. However, this is not usually practical on a tender, and impossible on a submarine.

- If leaks occur around a shaft, tighten the packing gland. Leakage at any other joint can be stopped only by removing the affected component and replacing O-rings.

- After a satisfactory pressure test, release internal pressure slowly, usually 1 hour, to avoid stirring up any dust in the scope.

- At some repair facilities, a hydrostatic pressure test of the outer head and taper tube/outer tube joint is mandatory. This test is conducted by slipping a specially constructed tank over the head section and upper portion of the outer tube.

The tank is sealed around the outer tube by a packing assembly similar to the hull gland. Long rods between the tank and a heavy plate on the bottom of the scope eyebox hold the unit in position during the test.

To conduct the test, fill the tank with water and apply a specified air pressure to duplicate seawater pressure at the required depth.

If the periscope has been reassembled correctly and if there are no hidden defects, the instrument will pass the hydrostatic test. If a leak occurs, you now have the problem of a flooded periscope to contend with, which will involve complete disassembly down to the last screw.

DRYING.–To remove traces of moisture, usually caused by the relative humidity in the optical shop, pull a vacuum on the scope after releasing test pressure. Under a vacuum, moisture vaporizes (boils) at a low temperature and can be easily withdrawn by a vacuum pump.

The vacuum pump is a rotary, positive-displacement, laboratory quality device capable of pulling a 0.01-mm vacuum. A CENCO HYVAC pump is the type usually used in optical shops.

Although the pump is capable of pulling very low vacuums on small areas, a periscope contains a large volume of empty space, with a small amount of moisture present. Therefore, vacuums of about 4 mm are usually satisfactory.

NOTE: Do not attempt to dry a periscope in a submarine if the outside temperature is below 50°F.

To assist with drying the periscope under vacuum, a heater blanket is often used on the periscope to raise the temperature, which improves the vaporization of moisture. The heater blanket is a heavy duty, rubberized, electric blanket long enough to cover the outer tube.

The following procedure applies to all types of periscopes.

- Position the heater blanket and turn it on.

- Attach the pump vacuum hose to the scope air outlet. Keep hoses as short as possible. Turn on the pump and allow it to run for several minutes before opening the air valve. Apply vacuum sealing wax (Apiezon) to all pump and hose fittings to eliminate possible vacuum leaks.

NOTE: The power supply to the vacuum pump must be on a circuit which automatically receives emergency power in case of a general power failure. If for any reason power is lost while pulling a vacuum, oil could be sucked from the pump into the periscope.

- Connect a vacuum gage to the periscope so you can constantly monitor the degree of vacuum. Bourdon tube vacuum gages can be used, but electronic gages are preferred since a higher accuracy can be obtained.

- Open the air outlet valve and proceed with pumping until a vacuum of 4 mm is reached. This may take from 2 to 4 hours.

- When the desired vacuum is reached, secure the air outlet valve, remove the vacuum hose, then secure the pump. Allow the periscope to sit for at least 3 hours under vacuum with heater blanket on; then recheck the vacuum. A changed (raised) vacuum reading usually indicates the presence of moisture vapor which was not drawn off during pumping. In this case, attach the vacuum pump and turn it on; then open the air outlet valve and pump the scope again to a 4-mm vacuum. After obtaining the proper vacuum, secure the pumping again and hold for 3 hours.

NOTE: Due to the humidity control in the optical shop, it is seldom necessary to pump a scope more than twice. If after repumping the vacuum again rises, there may be a defective seal in the scope which did not leak under pressure. You must disassemble the scope, inspect all seals, reassemble, then start the cycling procedure again.

CHARGING.–Once a periscope holds a vacuum for 3 hours, it can be filled with dry nitrogen (charged). This process is a little more complicated than merely attaching a nitrogen bottle and boosting pressure. Nitrogen from a bottle, no matter how pure, is not dry enough to charge a periscope. The gas must be dried by freezing out moisture as the gas circulates through a cold trap.

The cold trap, manufactured in your shop, consists of a large-mouthed 1 gallon thermos bottle which is surrounded on all sides by 2 inches of insulation in a suitable container. The lid of the container contains a coil of copper tubing which fits into the thermos bottle but does not touch the sides or bottom when the lid is on the container. Hose fittings on the inlet and outlet sides of the coil of tubing connect a nitrogen bottle to the cold trap and another hose between the cold trap and scope.

Place a mixture of dry ice and acetone in the thermos bottle (about the same consistency as slushy snow). When nitrogen is flowing through the cold trap coil in the mixture, all moisture is frozen out of the gas.

NOTE: The mixture of dry ice and acetone produces a temperature of around -74°C (-100°F). You must wear gloves and eye protection when mixing the solution, and when inserting the lid and coil, since violent boiling and splashing can occur. If this extremely cold solution touches your skin, you will receive a severe burn due to frostbite.

After a scope is charged, take a dewpoint reading of the nitrogen inside the scope to determine the temperature at which fogging will occur. A dewpoint temperature of at least -55°C is required.

Dewpoint and relative humidity are closely related. For instance, if air is saturated with water vapor, the relative humidity is 100%, and any slight lowering of air temperature will produce condensation. When air at any given temperature contains 50% of the vapor it could contain at the saturation point, the relative humidity is 50% and the temperature would have to be lowered considerably to produce condensation. The temperature at which air (or nitrogen) is saturated with water vapor to the point of condensation is called the dewpoint. In the case of a -55°C dewpoint for dry nitrogen, you can see that the amount of moisture present is extremely small.

The procedure for charging a periscope is as follows:

- Assemble all equipment for the job.
- Mix crushed dry ice and acetone in the cold trap. Leave sufficient room for the coil.
- Attach hoses to the cold trap coil and purge the coil for several minutes. While nitrogen is flowing through the coil, slowly lower the cold trap lid.
- Regulate the flow of nitrogen so just a trace can be felt on your moistened lip.
- Attach the hose to the scope inlet valve and slowly open the valve. You have a fairly high vacuum in the scope which will slowly pull dry nitrogen in until the vacuum breaks (pressure equalizes).

NOTE: Check the vacuum gage attached to the scope frequently to determine when pressures equalize.

- After the vacuum breaks, use a pressure gage on the scope and boost pressure in the scope to 10 psi.

NOTE: Use a flowmeter set for 3 to 5 cubic feet per minute, or boost a regulator in 4-pound steps every 5 minutes.

- When pressure reaches 10 psi, secure the charging valve and remove the cold trap hose. Pull the coil out of the cold trap but allow a slight flow of nitrogen to run through the coil until the coil reaches room temperature.

- Run a dewpoint check of the gas in the periscope.

NOTE: To conduct this test, use an electronic instrument (ALNOR DEWPOINTER). Follow the procedure outlined in the test instrument booklet. The procedure is quite simple. After running this test several times, you probably will not need to use the booklet again.

- When a satisfactory dewpoint is obtained (-55°C or below), bleed the internal pressure of the periscope to 7.5 psi.

NOTE: All periscopes are charged to 7.5 psi at 70°F. Pressures will vary from 7.1 psi at 60°F to 7.9 psi at 80°F.

- The cycling procedure is now complete. Secure all equipment.

NOTE: All periscopes should have a dewpoint check made every 6 months, even though no fogging has been noticed.

391

APPENDIX I

U. S. CUSTOMARY AND METRIC SYSTEM UNITS OF MEASUREMENTS

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (tĕr'ȧ)	T
1 000 000 000 = 10^{9}	giga (jĭ'gȧ)	G
1 000 000 = 10^{6}	mega (mĕg'ȧ)	M*
1 000 = 10^{3}	kilo (kĭl'ȯ)	k*
100 = 10^{2}	hecto (hĕk'tȯ)	h
10 = 10	deka (dĕk'ȧ)	da
0.1 = 10^{-1}	deci (dĕs'ĭ)	d
0.01 = 10^{-2}	centi (sĕn'tĭ)	c*
0.001 = 10^{-3}	milli (mĭl'ĭ)	m*
0.000 001 = 10^{-6}	micro (mī'krȯ)	μ*
0.000 000 001 = 10^{-9}	nano (năn'ȯ)	n
0.000 000 000 001 = 10^{-12}	pico (pē'kȯ)	p
0.000 000 000 000 001 = 10^{-15}	femto (fĕm'tȯ)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (ăt'tȯ)	a

*Most commonly used

ENGLISH AND METRIC SYSTEM UNITS OF MEASUREMENT COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents		Conversions Accurate to Parts Per Million (units stated in abbreviated form) Number X Factor	
1 inch	= 25 millimeters	in X 25.4*	= mm
1 foot	= 0.3 meter	ft X 0.3048*	= m
1 yard	= 0.9 meter	yd X 0.9144*	= m
1 mile†	= 1.6 kilometers	mi X 1.60934	= km
1 square inch	= 6.5 square centimeters	in^2 X 6.4516*	= cm^2
1 square foot	= 0.09 square meter	ft^2 X 0.0929030	= m^2
1 square yard	= 0.8 square meter	yd^2 X 0.836127	= m^2
1 acre	= 0.4 hectare	acres X 0.404686	= ha
1 cubic inch	= 16 cubic centimeters	in^3 X 16.3871	= cm^3
1 cubic foot	= 0.03 cubic meter	ft^3 X 0.0283168	= m^3
1 cubic yard	= 0.8 cubic meter	yd^3 X 0.764555	= m^3
1 quart (lq.)	= 1 liter	qt (lq.) X 0.946353	= *l*
1 gallon	= 0.004 cubic meter	gal X 0.00378541	= m^3
1 ounce (avdp)	= 28 grams	oz (avdp) X 28.3495	= g
1 pound (avdp)	= 0.45 kilogram	lb (avdp) X 0.453592	= kg
1 horsepower	= 0.75 kilowatt	hp X 0.745700	= kW
1 pound per square inch	= 0.07 kilogram per square centimeter	psi X 0.0703224	= kg/cm^2
1 millimeter	= 0.04 inch	mm X 0.0393701	= in
1 meter	= 3.3 feet	m X 3.28084	= ft
1 meter	= 1.1 yards	m X 1.09361	= yd
1 kilometer	= 0.6 mile	km X 0.621371	= mi
1 square centimeter	= 0.16 square inch	cm^2 X 0.155000	= in^2
1 square meter	= 11 square feet	m^2 X 10.7639	= ft^2
1 square meter	= 1.2 square yards	m^2 X 1.19599	= yd^2
1 hectare	= 2.5 acres	ha X 2.47105	= acres
1 cubic centimeter	= 0.06 cubic inch	cm^3 X 0.0610237	= in^3
1 cubic meter	= 35 cubic feet	m^3 X 35.3147	= ft^3
1 cubic meter	= 1.3 cubic yards	m^3 X 1.30795	= yd^3
1 liter	= 1 quart (lq.)	*l* X 1.05669	= qt (lq.)
1 cubic meter	= 250 gallons	m^3 X 264.172	= gal
1 gram	= 0.035 ounces (avdp)	g X 0.0352740	= oz (avdp)
1 kilogram	= 2.2 pounds (avdp)	kg X 2.20462	= lb (avdp)
1 kilowatt	= 1.3 horsepower	kW X 1.34102	= hp
1 kilogram per square centimeter	= 14.2 pounds per square inch	kg/cm^2 X 14.223226	= psi

†nautical mile = 1.852 kilometers

* exact

INDEX

A

Aberration, lens, 4-25 to 4-33
  astigmatism, 4-28, 4-29
  chromatic, 4-25, 4-26
  coma, 4-27, 4-28
  curvature of field, 4-29, 4-30
  distortion, 4-30, 4-31
  Newton's rings, 4-31 to 4-33
  spherical, 4-26, 4-27

Aberrations of the eye, 5-10, 5-11
  astigmatism, 5-10
  eye strain, 5-11
  hyperopia, 5-10
  myopia, 5-10

Advancement, 1-1 to 1-12
  Navy Enlisted Advancement System, the, 1-2 to 1-9
  Navy Enlisted Classification Codes, 1-2
  Opticalman rating, 1-1, 1-2
  Personnel Advancement Requirement (PAR) Program, NAVPERS 1414/4, 1-6 to 1-9
  Personnel Qualification Standards, 1-9
  purposes, benefits, and limitations of the Planned Maintenance System, 1-9, 1-10
  sources of information, 1-10 to 1-12

Aperture, relative, 4-23, 4-24
Assembling mechanical parts, 8-2, 8-3
Astigmatism, 4-28, 4-29

Astronomical telescopes, 5-17 to 5-20
  reflecting, 5-17, 5-18
  refracting, 5-18 to 5-20

Atmospheric refraction, 2-24 to 2-27
  heat waves, 2-27
  looming, 2-27
  mirages, 2-25 to 2-27
  rainbows, 2-27

Attitude, image, 3-3 to 3-5
  normal and erect, 3-4
  normal and inverted, 3-4
  reverted and erect, 3-4
  reverted and inverted, 3-4, 3-5
Azimuth and bearing circles, 10-13 to 10-18
  construction features, 10-14 to 10-16
  repair and adjustment, 10-16 to 10-18

B

Basic optical systems, 5-1 to 5-31

  eyepiece systems, 5-11 to 5-17
    basic function, 5-11 to 5-13
    nomenclature, 5-13
    types, 5-13 to 5-17

  eye structure, 5-1 to 5-11
    aberrations of the eye, 5-10, 5-11
    iris function, 5-2
    optical instrument, 5-3
    refracting mechanism, 5-2
    stereoscopic vision, 5-6 to 5-10
    vision, 5-3 to 5-6
    visual acuity, 5-6

  human eye, the, 5-1
  simple telescopes, 5-17 to 5-31
    astronomical, 5-17 to 5-20
    gunsight telescopes, 5-26, 5-27
    magnification, 5-27 to 5-30
    microscope, 5-30, 5-31
    terrestrial telescopes, 5-20 to 5-26

Bearings, 6-17 to 6-19
  ball bearings, 6-18, 6-19
  rotational bearing, 6-17, 6-18
  sliding surface bearings, 6-17
Bed, lathe, 9-11, 9-12

Binoculars, 10-34 to 10-46
    collimation, 10-42 to 10-44
    construction features, 10-35 to 10-39
    overhaul, 10-39 to 10-42
    7 X 50 binoculars, 10-35
    ship mounted binoculars, 10-44 to 10-46
Blinder assembly, periscopes, 12-17
Boresight telescopes, 10-46 to 10-49
    construction features, 10-46 to 10-49
    repair and adjustment, 10-49
Brazing and soldering, 7-21 to 7-24

C

Carriage, 9-15, 9-16
Cementing and cleaning, lens, 7-35 to 7-40
Charging procedures, optical instruments, 8-15 to 8-19
    drying and charging, 8-17, 8-18
    general safety precautions, 8-19
    pressure testing and charging rangefinders, 8-18, 8-19
    securing the equipment, 8-18
Charging, sealing and drying, 8-13 to 8-19
Chromatic aberrations, 4-25, 4-26
Cleaning and painting, 7-30 to 7-35
    baking procedure, 7-35
    corrosion removal, 7-30, 7-31
    finish defects, 7-35
    instrument painting, 7-34, 7-35
    paint removal, 7-32, 7-33
    preparing paint, 7-33, 7-34
    safety precautions for using chemicals, 7-31, 7-32
    types of paint, 7-33
Cleaning, periscopes, 12-35 to 12-37
Collimation, 8-3 to 8-13
    adjustment, 8-9, 8-10
    equipment, 8-3 to 8-9
    procedures, 8-10 to 8-13
Color of light, 2-11, 2-12
Coma, 4-27, 4-28
Compass, magnetic, 10-4 to 10-13
Construction and design, optical instruments, 6-1 to 6-27
Corrosion removal, 7-30, 7-31
Crew Served Weapon Sight (CSWS), 11-7
Curvature, lens, 4-5
Curvature of field, 4-29, 4-30
Cutting tools, 9-22 to 9-24
Cylindrical lenses, 4-14, 4-15

D

Design and construction, optical instruments, 6-1 to 6-27
    lubrication, 6-26, 6-27
    mechanical features, 6-1 to 6-7
        body housing, 6-1 to 6-5
        diaphragms, 6-5 to 6-7
        shades and caps, 6-5
    mounting optical elements, 6-7 to 6-26
        bearings, 6-17 to 6-19
        fixed eyepiece mount, 6-16, 6-17
        focusing arrangements, 6-11 to 6-16
        helical gears, 6-21
        instrument sealing methods, 6-22
        lens mounts, 6-7 to 6-10
        optical instrument gears, 6-19 to 6-21
        O-rings, 6-24, 6-25
        packing, 6-25, 6-26
        preformed gaskets, 6-23, 6-24
        prism mounts, 6-10, 6-11
        sealing compound, 6-22, 6-23
Disassembly and repair, periscopes, 12-28 to 12-35
Diopter, lens, 4-22, 4-23
Distortion, 4-30, 4-31
Drill presses, 9-5 to 9-10
Drying, charging and sealing, 8-13 to 8-19

E

Eye structure, 5-1 to 5-11
    aberrations of the eye, 5-10, 5-11
    iris function, 5-2
    optical instrument, 5-3
    refracting mechanism, 5-2
    stereoscopic vision, 5-6 to 5-10
    vision, 5-3 to 5-6
    visual acuity, 5-6
Eyepiece systems, 5-11 to 5-17
    basic function, 5-11 to 5-13
    nomenclature, 5-13
    types, 5-13 to 5-17

F

Final assembly, periscopes, 12-44 to 12-47
Fixed eyepiece mount, 6-16, 6-17
Fluxes, 7-23, 7-24
Focal length, lens, 4-5 to 4-7, 4-18, 4-19

- Focusing arrangements, 6-11 to 6-16
  - draw tube, 6-12, 6-13
  - internal focusing mount, 6-15, 6-16
  - multiple lead thread, 6-14, 6-15
  - spiral (helical) keyway, 6-13, 6-14
- Focusing knob assembly, periscopes, 12-19 to 12-21
- Formulas, lens, 4-18 to 4-24
- Frequency and wavelength, 2-7, 2-8

G

- Gaskets, preformed, 6-23, 6-24
- Gas-tight instruments, 8-13, 8-14
- Gears, optical instrument, 6-19 to 6-21
- Glass, properties of, 4-1 to 4-3
- Grinders, 9-1 to 9-5
- Gunsight telescopes, 5-26, 5-27
- Gunsights and night vision sights, 11-1 to 11-12

H

- Headstock, 9-12, 9-13
- Heat treating and tempering, 7-24 to 7-29
  - ferrous materials, 7-26
  - heat treating processes, 7-27 to 7-29
  - nonferrous materials, 7-26, 7-27
- Helical gears, 6-21
- Human eye, the, 5-1

I

- Image description, 3-3 to 3-5
  - image attitude, 3-3 to 3-5
  - real image, 3-3
  - virtual image, 3-3
- Image formation, 4-9 to 4-14
- Information, sources of, 1-10 to 1-12
- Inner tube removal, periscopes, 12-26 to 12-27
- Inspection and testing, 7-1 to 7-9
  - chromatic aberration, 7-9
  - coma, 7-9
  - distortion, 7-9
  - illumination and contrast, 7-8
  - image fidelity, 7-6 to 7-8
  - mechanical condition, 7-2
  - optical system, 7-2 to 7-6
  - spherical aberration, 7-8, 7-9
- Iris function, 5-2

K

- Knee and column type milling machines, 9-41, 9-42

L

- Lathes, 9-10 to 9-41
  - attachments and accessories, 9-16 to 9-22
    - carriage stop, 9-21
    - center rest, 9-20
    - collets, 9-17, 9-18
    - follower rest, 9-20
    - lathe centers, 9-21, 9-22
    - mandrels, 9-22
    - taper attachment, 9-18 to 9-20
    - thread dial indicator, 9-21
  - cutting tools, 9-22 to 9-24
    - finish cuts, 9-27
  - knowledge of operation, 9-24 to 9-28
    - lubricants, 9-27
    - maintenance, 9-27, 9-28
    - rough cuts, 9-27
    - speeds and feeds, 9-26
  - operation, 9-28 to 9-40
    - boring, 9-33, 9-34
    - center drilling, 9-29
    - centering the work, 9-28, 9-29
    - facing, 9-32, 9-33
    - mounting work, 9-28
    - setting the cutting tool, 9-31
    - tapering, 9-34 to 9-36
    - threading, 9-36 to 9-40
    - turning, 9-31, 9-32
    - turning between centers, 9-29 to 9-31
  - principal parts, 9-11 to 9-16
    - bed, 9-11, 9-12
    - carriage, 9-15, 9-16
    - headstock, 9-12, 9-13
    - quick-change gears, 9-15
    - tailstock, 9-13 to 9-15
  - safety precautions, 9-40, 9-41
- Left training handle assembly, periscopes, 12-21 to 12-23
- Lens cleaning and cementing, 7-35 to 7-40
  - cementing equipment and materials, 7-38 to 7-40
  - cleaning equipment, 7-35 to 7-37
  - cleaning procedure, 7-37, 7-38

Lens mounts, 6-7 to 6-10
  eccentric mount, 6-9, 6-10
  retainer rings, 6-8, 6-9
  screw adjusting mounts, 6-9
Lens replacement, 8-1
Lenses, 4-1 to 4-38
  aberrations, 4-25 to 4-33
    astigmatism, 4-28
    coma, 4-27, 4-28
    chromatic, 4-25, 4-26
    curvature of field, 4-29, 4-30
    distortion, 4-30, 4-31
    Newton's rings, 4-31 to 4-33
    spherical, 4-26, 4-27
  formulas, 4-18 to 4-24
    focal length, 4-18, 4-19
    lens diopter, 4-22, 4-23
    magnification, 4-19 to 4-22
    magnifying power, 4-22
    relative aperture, 4-23, 4-24
    relative image brightness, 4-24
  properties of glass, 4-1 to 4-3
    optical qualities, 4-2, 4-3
    physical properties, 4-1, 4-2
  terminology, 4-4 to 4-18
    curvature, 4-5
    cylindrical lenses, 4-14, 4-15
    focal length, 4-5 to 4-7
    image formation, 4-9 to 4-14
    negative lenses, 4-7, 4-8
    positive lenses, 4-7
    radius of curvature, 4-5
    spherical mirrors, 4-15 to 4-18
  thick lenses, 4-33 to 4-38
    back focal length, 4-33, 4-34
    compound lenses, 4-34, 4-35
    equivalent focal length, 4-33
    front focal length, 4-33
    lens combinations, 4-35 to 4-37
    miscellaneous optical elements, 4-37, 4-38
Light, the nature of, 2-1 to 2-28
Lubrication, 6-26, 6-27

M

Machine tool operation, 9-1 to 9-54
  drill presses, 9-5 to 9-10
  grinders, 9-1 to 9-5
Machine tool operation—Continued
  lathes, 9-10 to 9-41
    attachments and accessories, 9-16 to 9-22
    cutting tools, 9-22 to 9-24
    knowledge of operation, 9-24 to 9-28
    operation, 9-28 to 9-40
    principal parts, 9-11 to 9-16
    safety precautions, 9-40, 9-41
  milling machines, 9-41 to 9-54
    knee and column type, 9-41, 9-42
    operation, 9-46 to 9-53
    precautions, 9-54
    standard equipment, 9-42 to 9-46
Magnetic compass, 10-4 to 10-13
  inspection and disassembly, 10-6 to 10-8
  repair and assembly, 10-8 to 10-11
  testing and adjusting, 10-11 to 10-13
Magnification, 4-19 to 4-22
Magnification, telescope, 5-27 to 5-30
Maintenance procedures—part I, 7-1 to 7-40
  cleaning and painting, 7-30 to 7-35
  heat treating and tempering, 7-24 to 7-29
  inspection and testing, 7-1 to 7-9
  lens cleaning and cementing, 7-35 to 7-40
  overhaul and repair, 7-9 to 7-21
  soldering and brazing, 7-21 to 7-24
Maintenance procedures—part II, 8-1 to 8-19
  collimation, 8-3 to 8-13
    adjustment, 8-9, 8-10
    equipment, 8-3 to 8-9
    procedures, 8-10 to 8-13
  reassembly, 8-1 to 8-3
    assembling mechanical parts, 8-2, 8-3
    replacing lenses, 8-1
    replacing prisms, 8-1, 8-2
  sealing, drying, and charging, 8-13 to 8-19
    charging procedures, 8-15 to 8-19
    gas-tight, 8-13, 8-14
    moisture-tight, 8-13
    pressure-tight, 8-14
    safety procedures for handling cylinders, 8-14, 8-15
Measurements in optics, 3-1 to 3-3
  degree system, 3-3
  metric system, 3-1, 3-2
  Navy mil, 3-3

Mechanical features, optical instruments, 6-1 to 6-7
  body housing, 6-1 to 6-5
  diaphragms, 6-5 to 6-7
  shades and caps, 6-5
Metascope, 11-7
Microscope, the, 5-30, 5-31

Milling machines, 9-41 to 9-54
  knee and column type, 9-41, 9-42
  operation, 9-46 to 9-53
    direction of cutter rotation, 9-49, 9-50
    feeds and speeds, 9-50, 9-51
    indexing, 9-51 to 9-53
    setup procedures, 9-48, 9-49
  precautions, 9-54

  standard equipment, 9-42 to 9-46
    circular milling attachment, 9-46
    index head, 9-44, 9-45
    milling cutters, 9-46
    universal milling attachment, 9-45
    vises, 9-42

Mirrors and prisms, 3-1 to 3-16
  image description, 3-3 to 3-5
    image attitude, 3-3 to 3-5
    real image, 3-3
    virtual image, 3-3

  image transmission, 3-5 to 3-16
    penta prism, 3-13 to 3-16
    plane mirrors, 3-5 to 3-8
    reflecting prisms, 3-9 to 3-13
    refracting prisms, 3-8, 3-9
    rhomboid prism, 3-13

  measurements in optics, 3-1 to 3-3
    degree system, 3-3
    metric system, 3-1, 3-2
    Navy mil, 3-3

Mirrors, spherical, 4-15 to 4-18

Mk 36 NVS, 11-1

Mk 37 NVS, 11-1

Mk 67 and Mk 68 gunsights, 11-4 to 11-6

Mk 97 telescope, 11-6, 11-7

Mk 100 telescope, 11-7

Mk 102 and Mk 116 telescopes, 11-7 to 11-12

Moisture-tight instruments, 8-13

Mounting optical elements, 6-7 to 6-26
  bearings, 6-17 to 6-19
  fixed eyepiece mount, 6-16, 6-17
  focusing arrangements, 6-11 to 6-16
  helical gears, 6-21
  instrument sealing methods, 6-22
  lens mounts, 6-7 to 6-10
  optical instrument gears, 6-19 to 6-21
  O-rings, 6-24, 6-25
  packing, 6-25, 6-26
  preformed gaskets, 6-23, 6-24
  prism mounts, 6-10, 6-11
  sealing compound, 6-22, 6-23

N

Nature of light, the, 2-1 to 2-28
  color of light, 2-11, 2-12
  reflection, 2-14 to 2-16
  refraction, 2-16 to 2-28
  sources of light, 2-2 to 2-5
  speed of light, 2-8 to 2-11
  theories of light, 2-1, 2-2
  transmission of light, 2-5, 2-6
  visibility of objects, 2-12 to 2-14
  wavelength and frequency, 2-7, 2-8

NAVEDTRA 10052, 1-10 to 1-12
NAVEDTRA publications, 1-10
Navigation and optical equipment, 10-1 to 10-48
Navy Enlisted Advancement System, the, 1-2 to 1-9
  how to prepare for advancement, 1-5, 1-6
  Personnel Advancement Requirement (PAR) program, NAVPERS 1414/4, 1-6 to 1-9
  qualifying for advancement, 1-2
  who will be advanced?, 1-5

Navy Enlisted Classification Codes, 1-2
Negative lenses, 4-7, 4-8
Newton's rings, 4-31 to 4-33
Night vision sights and gunsights, 11-1 to 11-12
  components, 11-1
  Crew Served Weapon Sight (CSWS), 11-2
  gunsight telescopes, 11-4 to 11-12
    Mk 97 telescope, 11-6, 11-7
    Mk 100 telescope, 11-7
    Mk 102 and Mk 116 telescopes, 11-7 to 11-12

    Mk 67 and Mk 68 gunsights, 11-4 to 11-6
  metascope, 11-2

Night vision sights and gunsights—Continued
  Mk 37 NVS, 11-1
  Mk 36 NVS, 11-1
  repair and adjustment, 11-2 to 11-4

O

OOD and QM spyglasses, 10-23 to 10-29
  construction features, 10-23 to 10-25
  disassembly, 10-25 to 10-28
  repair, reassembly, and collimation, 10-28, 10-29
Optic measurements, 3-1 to 3-3
Optical and navigation equipment, 10-1 to 10-49
  azimuth and bearing circles, 10-13 to 10-18
  binoculars, 10-34 to 10-46
  boresight telescopes, 10-46 to 10-49
  magnetic compass, 10-4 to 10-13
  OOD and QM spyglasses, 10-23 to 10-29
  parallel motion protractor, 10-1 to 10-4
  sextant, 10-20 to 10-23
  ship telescope, 10-29 to 10-32
  stadimeter, 10-18 to 10-20
  telescope alidade, 10-32 to 10-34

Optical systems, basic, 5-1 to 5-31
Opticalman rating, 1-1, 1-2
O-rings, 6-24, 6-25
Overhaul and repair, 7-9 to 7-21
  common tools, 7-10
  disassembly, 7-14 to 7-18
  repair procedure, 7-18 to 7-21
  special tools, 7-10 to 7-14

P

Packing, 6-25, 6-26
Painting and cleaning, 7-30 to 7-35
Parallel motion protractor, 10-1 to 10-4
  disassembly, 10-1 to 10-3
  inspection, cleaning, repair, reassembly, 10-3, 10-4
Penta prism, 3-13 to 3-16
  prism defects, 3-16
  roof edge prism, 3-15
  Schmidt prism, 3-16
Periscope cycling, 12-47 to 12-50
Periscope eyepieces, 12-16
Periscopes, submarine, 12-1 to 12-50
  handling, 12-6 to 12-15
    auxiliary handling equipment, 12-11
    external fittings replacement, 12-15
    installation, 12-13
    packing, 12-12
    removal, 12-8 to 12-11
    repacking, 12-14
  repair, 12-15 to 12-50
    external fitting overhaul, 12-15 to 12-25
    maintenance, 12-25 to 12-50
  theory and design, 12-1 to 12-5
Personnel Qualification Standards, 1-9
Plane mirrors, 3-5 to 3-8
Positive lenses, 4-7
Preformed gaskets, 6-23, 6-24
Preparing for advancement, how to, 1-5, 1-6
Pressure gage and valve assembly, periscopes, 12-19
Prism mounts, 6-10, 6-11
  porro prism mounts, 6-11
  right-angled, 6-10
  roofedge, 6-10
Prism replacement, 8-1, 8-2
Prisms and mirrors, 3-1 to 3-16
Purposes, benefits, and limitations of the Planned Maintenance System, 1-9, 1-10

Q

QM and OOD spyglasses, 10-23 to 10-29
Quick-change gears, 9-15

R

Real image, 3-3
Reassembly and collimation, periscopes, 12-37 to 12-43
Reassembly, instrument, 8-1 to 8-3
  assembling mechanical parts, 8-2, 8-3
  replacing lenses, 8-1
  replacing prisms, 8-1, 8-2
Reflecting prisms, 3-9 to 3-13
  dove prism, 3-12, 3-13
  porro prism, 3-12
  right-angled prism, 3-11, 3-12
Reflection, 2-14 to 2-16
  diffuse, 2-16
  law of, 2-15
  regular, 2-15

399

Refracting prisms, 3-8, 3-9
    prism diopter, 3-9
    wedge, 3-9
Refraction, 2-16 to 2-28
    angle of, 2-20, 2-21
    atmospheric refraction, 2-24 to 2-27
        heat waves, 2-27
        looming, 2-27
        mirages, 2-25 to 2-27
        rainbows, 2-27
    index of, 2-19, 2-20
    laws of, 2-17 to 2-19
    reflection and refraction combined, 2-21 to 2-23
    total internal reflection, 2-23, 2-24
Relative image brightness, 4-24
Repair and overhaul, 7-9 to 7-21
Rhomboid prism, 3-13
Right training handle assembly, periscopes, 12-23, 12-24

S

Sealing, drying and charging, 8-13 to 8-19
    charging procedures, 8-15 to 8-19
    gas-tight, 8-13, 8-14
    moisture-tight, 8-13
    pressure-tight, 8-14
    safety procedures for handling cylinders, 8-14, 8-15
Sealing methods, instrument, 6-22
Sextant, 10-20 to 10-23
    construction features, 10-21
    repair and adjustment, 10-21 to 10-23
Ship telescope, 10-29 to 10-32
    construction features, 10-29 to 10-32
    repair and adjustment, 10-32
Soldering and brazing, 7-21 to 7-24
    fluxes, 7-23, 7-24
    silver brazing techniques, 7-24
    silver soldering and brazing, 7-21, 7-22
    soft soldering, 7-21
Sources of light, 2-2 to 2-5
    artificial, 2-3 to 2-5
    natural, 2-2, 2-3
Speed of light, 2-8 to 2-11
    Michelson's measurements, 2-10, 2-11
    Roemer's measurement, 2-10
Spherical aberrations, 4-26, 4-27
Spherical mirrors, 4-15 to 4-18
Stadimeter, 10-18 to 10-20
    construction, 10-19
    repair and adjustment, 10-19, 10-20
Stadimeter collimation, periscopes, 12-43
Stadimeter dial and drive assembly, periscopes, 12-23, 12-25
Stereoscopic vision, 5-6 to 5-10
Structure of the eye, 5-1 to 5-11
Submarine periscopes, 12-1 to 12-50
    periscope handling, 12-6 to 12-15
        auxiliary handling equipment, 12-11
        external fittings replacement, 12-15
        periscope installation, 12-13
        periscope packing, 12-12
        removal, 12-8 to 12-11
        repacking the periscope, 12-14
    periscope identification, 12-6
    periscope repair, 12-15 to 12-50
        external fitting overhaul, 12-15 to 12-25
        maintenance, 12-25 to 12-50
    theory and design, 12-1 to 12-5

T

Tailstock, 9-13 to 9-15
Telescope alidade, 10-32 to 10-34
    construction features, 10-32 to 10-34
    repair and adjustment, 10-34
Telescope, ship, 10-29 to 10-32
Telescopes, boresight, 10-46 to 10-49
Telescopes, gunsight, 11-4 to 11-12
    Mk 97 telescope, 11-6, 11-7
    Mk 100 telescope, 11-7
    Mk 102 and Mk 116 telescopes, 11-7 to 11-12
    Mk 67 and Mk 68 gunsights, 11-4 to 11-6
Telescopes, simple, 5-17 to 5-31
    astronomical, 5-17 to 5-20
    gunsight telescopes, 5-26, 5-27
    magnification, 5-27 to 5-30
    microscope, 5-30, 5-31
    terrestrial telescopes, 5-20 to 5-26
Tempering and heat treating, 7-24 to 7-29
Terminology, lens, 4-4 to 4-18
Terrestrial telescopes, 5-20 to 5-26
    Galilean telescope, 5-20
    lens erecting systems, 5-20 to 5-23
    prism erecting systems, 5-25, 5-26
    two-erector, 5-23, 5-24
    variable power, 5-24, 5-25

Testing and inspection, 7-1 to 7-9
Theories of light, 2-1, 2-2
    electromagnetic theory, 2-2
    particles and waves, 2-1
    quantum theory, 2-2
Thick lenses, 4-33 to 4-38
Transmission of images, 3-5 to 3-16
    penta prism, 3-13 to 3-16
    plane mirrors, 3-5 to 3-8
    reflecting prisms, 3-9 to 3-13
    refracting prisms, 3-8, 3-9
    rhomboid prism, 3-13
Transmission of light, 2-5, 2-6

U

U.S. Customary and Metric System Units of Measurements, AI-1, AI-2

V

Variable density filter attachment, periscopes, 12-18

Virtual image, 3-3

Visibility of objects, 2-12 to 2-14
    opaque, 2-13
    translucent, 2-13
    transparent, 2-14

Vision, 5-3 to 5-6
    color blindness, 5-5, 5-6
    color vision, 5-5
    night vision, 5-5

Vision, color, 2-12

W

Wavelength and frequency, 2-7, 2-8

Wheels, grinding, 9-3 to 9-5
    abrasives, 9-3
    bond, 9-3, 9-4
    grain size, grade, and structure, 9-4
    installation, 9-4
    maintenance, 9-5

401

OPTICALMAN 3&2

NAVEDTRA 10205-B

Prepared by the Naval Education and Training Program Development
Center, Pensacola, Florida

Your NRCC contains a set of assignments and self-scoring answer sheets (packaged separately). The Rate Training Manual, Opticalman 3&2 NAVEDTRA 10205-B , is your textbook for the NRCC. If an errata sheet comes with the NRCC, make all indicated changes or corrections. Do not change or correct the textbook or assignments in any other way.

HOW TO COMPLETE THIS COURSE SUCCESSFULLY

Study the textbook pages given at the beginning of each assignment before trying to answer the items. Pay attention to tables and illustrations as they contain a lot of information. Making your own drawings can help you understand the subject matter. Also, read the learning objectives that precede the sets of items. The learning objectives and items are based on the subject matter or study material in the textbook. The objectives tell you what you should be able to do by studying assigned textual material and answering the items.

At this point you should be ready to answer the items in the assignment. Read each item carefully. Select the BEST ANSWER for each item, consulting your textbook when necessary. Be sure to select the BEST ANSWER from the subject matter in the textbook. You may discuss difficult points in the course with others. However, the answer you select must be your own. Use only the self-scoring answer sheet designated for your assignment. Follow the scoring directions given on the answer sheet itself and elsewhere in this course.

Your NRCC will be administered by your command or, in the case of small commands, by the Naval Education and Training Program Development Center. No matter who administers your course you can complete it successfully by earning grades that average 3.2 or higher. If you are on active duty, the average of your grades in all assignments must be at least 3.2. If you are NOT on active duty, the average of your grades in all assignments of each creditable unit must be at least 3.2. The unit breakdown of the course, if any, is shown later under Naval Reserve Retirement Credit.

WHEN YOUR COURSE IS ADMINISTERED BY LOCAL COMMAND

As soon as you have finished an assignment, submit the completed self-scoring answer sheet to the officer designated to administer it. He will check the accuracy of your score and discuss with you the items that you do not understand. You may wish to record your score on the assignment itself since the self-scoring answer sheet is not returned.

If you are completing this NRCC to become eligible to take the fleetwide advancement examination, follow a schedule that will enable you to complete all assignments in time. Your schedule should call for the completion of at least one assignment per month.

Although you complete the course successfully, the Naval Education and Training Program Development Center will not issue you a letter of satisfactory completion. Your command will make a note in your service record, giving you credit for your work.

WHEN YOUR COURSE IS ADMINISTERED BY THE NAVAL EDUCATION AND TRAINING PROGRAM DEVELOPMENT CENTER

After finishing an assignment, go on to the next. Retain each completed self-scoring answer sheet until you finish all the assignments in a unit (or in the course if it is not divided into units). Using the envelopes provided, mail your self-scored answer sheets to the Naval Education and Training Program Development Center where the scores will be verified and recorded. Make sure all blanks at the top of each answer sheet are filled in. Unless you furnish all the information required, it will be impossible to give you credit for your work. You may wish to record your scores on the assignments since the self-scoring answer sheets are not returned.

The Naval Education and Training Program Development Center will issue a letter of satisfactory completion to certify successful completion of the course (or a creditable unit of the course). To receive a course-completion letter, follow the directions given on the course-completion form in the back of this NRCC.

You may keep the textbook and assignments for this course. Return them only in the event you disenroll from the course or otherwise fail to complete the course. Directions for returning the textbook and assignments are given on the book-return form in the back of this NRCC.

PREPARING FOR YOUR ADVANCEMENT EXAMINATION

Your examination for advancement is based on the Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards (NAVPERS 18068). The sources of questions in this examination are given in the Bibliography for Advancement Study (NAVEDTRA 10052). Since your NRCC and textbook are among the sources listed in this bibliography, be sure to study both in preparing to take your advancement examination. The qualifications for your rating may have changed since your course and textbook were printed, so refer to the latest editions of NAVPERS 18068 and NAVEDTRA 10052.

NAVAL RESERVE RETIREMENT CREDIT

This course is evaluated at 32 Naval Reserve retirement points. These points are creditable to personnel eligible to receive them under current directives governing retirement of Naval Reserve personnel. Points will be credited in units as follows:

Unit 1: 12 points upon satisfactory completion of Assignments 1 through 6.

Unit 2: 12 points upon satisfactory completion of Assignments 7 through 12.

Unit 3: 8 points upon satisfactory completion of Assignments 13 through 16.

COURSE OBJECTIVE

By obtaining the correct answers to the questions in this course you will have developed your ability to overhaul, repair, calibrate, and perform other maintenance operations on the following types of optical equipment:

Telescopes
Binoculars
Navigation instruments
Gunsights
Rangefinders
Periscopes
Night vision equipment

While working on this nonresident career course, you may refer freely to the text. You may seek advice and instruction from others on problems arising in the course, but the solutions submitted must be the result of your own work and decisions. You are prohibited from referring to or copying the solutions of others, or giving completed solutions to anyone else taking the same course.

Naval nonresident career courses may include a variety of items -- multiple-choice, true-false, matching, etc. The items are not grouped by type; regardless of type, they are presented in the same general sequence as the textbook material upon which they are based. This presentation is designed to preserve continuity of thought, permitting step-by-step development of ideas. Some courses use many types of items, others only a few. The student can readily identify the type of each item (and the action required of him) through inspection of the samples given below.

MULTIPLE-CHOICE ITEMS

Each item contains several alternatives, one of which provides the best answer to the item. Select the best alternative and erase the appropriate box on the answer sheet.

SAMPLE

s-1. The first person to be appointed Secretary of Defense under the National Security Act of 1947 was
1. George Marshall
2. James Forrestal
3. Chester Nimitz
4. William Halsey

The erasure of a correct answer is indicated in this way on the answer sheet:

	1 T	2 F	3	4	
s-1	■	C	■	■	

TRUE-FALSE ITEMS

Determine if the statement is true or false. If any part of the statement is false the statement is to be considered false. Erase the appropriate box on the answer sheet as indicated below.

SAMPLE

s-2. Any naval officer is authorized to correspond officially with a bureau of the Navy Department without his commanding officer's endorsement.

The erasure of a correct answer is also indicated in this way on the answer sheet:

	1 T	2 F	3	4	
s-2	■	CC	■	■	

MATCHING ITEMS

Each set of items consists of two columns, each listing words, phrases or sentences. The task is to select the item in column B which is the best match for the item in column A that is being considered. Items in column B may be used once, more than once, or not at all. Specific instructions are given with each set of items. Select the numbers identifying the answers and erase the appropriate boxes on the answer sheet.

SAMPLE

In items s-3 through s-6, match the name of the shipboard officer in column A by selecting from column B the name of the department in which the officer functions.

A. Officers	B. Departments
s-3. Damage Control Assistant	1. Operations Department
s-4. CIC Officer	2. Engineering Department
s-5. Assistant for Disbursing	3. Supply Department
s-6. Communications Officer	

The erasure of a correct answer is indicated in this way on the answer sheet:

	1 T	2 F	3	4	
s-3	■	C	■	■	
s-4	C	■	■	■	
s-5	■	■	C	■	
s-6	C	■	■	■	

How To Score Your Immediate Knowledge of Results (IKOR) Answer Sheets

	1 T	2 F	3	4	
1	■	C	6	■	1
2	C	9	■	9	2
3	■	■	C	■	
4	CC	12	■	■	1

Total the number of incorrect erasures (those that show page numbers) for each item and place in the blank space at the end of each item.

Sample only

Number of boxes erased incorrectly	0-2	3-7	8-
Your score	4.0	[✓ 3.9]	3.8

Now TOTAL the column(s) of incorrect erasures and find your score in the Table at the bottom of EACH answer sheet.

NOTICE: If, on erasing, a page number appears, review text (starting on that page) and erase again until "C", "CC", or "CCC" appears. For courses administered by the Center, the maximum number of points (or incorrect erasures) will be deducted from each item which does NOT have a "C", "CC", or "CCC" uncovered (i.e., 3 pts. for four choice items, 2 pts. for three choice items, and 1 pt. for T/F items).

404

Assignment 1

Advancement and The Nature of Light

Textbook Assignment: Pages 1-1 through 2-2

In this course you will demonstrate that learning has taken place by correctly answering training items. The mere physical act of indicating a choice on an answer sheet is not in itself important; it is the mental achievement, in whatever form it may take, prior to the physical act that is important and toward which course learning objectives are directed. The selection of the correct choice for a course training item indicates that you have fulfilled, at least in part, the stated objective(s).

The accomplishment of certain objectives, for example, a physical act such as drafting a memo, cannot readily be determined by means of objective type course items; however, you can demonstrate by means of answers to training items that you have acquired the requisite knowledge to perform the physical act. The accomplishment of certain other learning objectives, for example, the mental acts of comparing, recognizing, evaluating, choosing, selecting, etc., may be readily demonstrated in a course by indicating the correct answers to training items.

The comprehensive objective for this course has already been given. It states the purpose of the course in terms of what you will be able to do as you complete the course.

The detailed objectives in each assignment state what you should accomplish as you progress through the course. They may appear singly or in clusters of closely related objectives, as appropriate; they are followed by items which will enable you to indicate your accomplishment.

All objectives in this course are learning objectives and items are teaching items. They point out important things, they assist in learning, and they should enable you to do a better job for the Navy.

This self-study course is only one part of the total Navy training program; by its very nature it can take you only part of the way to a training goal. Practical experience, schools, selected reading, and the desire to accomplish are also necessary to round out a fully meaningful training program.

Learning Objective: Identify the two overall types of ratings, duties and responsibilities of an Opticalman and the purpose and sources of information pertaining to advancement. Textbook pages 1-1 through 1-9.

1-1. Study of the Opticalman rating includes learning which of the following operations?

1. Collimation, sealing, and drying
2. Inspection, disassembly, and repair
3. Replacement or manufacture of parts
4. All of the above

1-2. What is the lowest Opticalman rating that carries responsibility for the maintenance of records and logs in the shop?

1. OM3
2. OM2
3. OM1
4. OMC

1-3. Responsibility for administering an optical shop generally begins at the

1. E-4 level
2. E-5 level
3. E-6 level
4. E-7 level

1-4. As you advance in the Opticalman rating, you will be given greater responsibility and one way to prepare for this is by observing the work of Opticalmen at higher levels.

1-5. When should shop safety be emphasized?

1. Occasionally
2. When working with power tools
3. Always
4. When working with junior personnel

405

1-6. The rate training manual is organized around the skills of an Opticalman. Which document describes the minimum skills required of an Opticalman?

1. NAVPERS 18068-D, Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards
2. BUPERS Notice 1418
3. NAVEDTRA 10052, Bibliography for Advancement Study
4. NAVEDTRA 10056, Military Requirements for Petty Officer 3&2

1-7. Who details personnel who have acquired Opticalman skills to fill billets that require these skills?

1. Chief of Naval Personnel
2. Deputy Chief of Naval Operations (Manpower)
3. Enlisted Personnel Distribution Officers
4. Chief of Naval Operations

1-8. Your advancement in rate is important to you and to the Navy. What is the primary reason the Navy wishes you to advance?

1. You become more valuable as a trainer
2. You become more valuable as a specialist
3. You become eligible for shore patrol
4. Your job becomes more interesting

1-9. Which publication will normally keep you up-to-date on changes in the advancement system?

1. NAVPERS 18068-D, Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards
2. BUPERS Notice 1418
3. NAVEDTRA 10052, Bibliography for Advancement Study
4. NAVEDTRA 10056, Military Requirements for Petty Officer 3&2

1-10. Which of the following best expresses the advantages of advancement?

1. An increase in pay
2. More interesting and challenging assignments
3. Self-satisfaction that comes with increased responsibility
4. All of the above

1-11. Which of the following factors is NOT always a requirement to qualify for advancement to OM3?

1. Completion of a specified nonresident career course
2. Passing a written examination
3. Length of time in grade
4. Length of time in service

1-12. An OM3 preparing for the servicewide examination for advancement to OM2 should expect to be tested on the

1. military requirements and professional qualifications for OM2
2. military requirements for OM3 and OM2 and the professional qualifications for OM2
3. professional qualifications for OM3 and OM2 and the military requirements for OM2
4. military requirements and professional qualifications for OM3 and OM2

1-13. Where can you find a current list of the naval standards for advancement?

1. BUPERS Notice 1418
2. NAVEDTRA 10052, Bibliography for Advancement Study
3. NAVPERS 18068-D, Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards
4. NAVEDTRA 10056, Military Requirements for Petty Officer 3&2

1-14. What factor(s) determine(s) your final multiple score?

1. Your score on advancement examination
2. Your length of time in service
3. Your performance marks
4. All of the above

1-15. For you to make OM2 you must have how much time in service?

1. 18 mos
2. 2 yrs
3. 3 yrs
4. 30 mos

1-16. How much time in service is required for advancement to OM3?

1. 1 yr
2. 2 yrs
3. 18 mos
4. 30 mos

1-17. Personnel Advancement Requirements (PAR) must be completed for advancement to

1. E-4 through E-7
2. E-4 through E-9
3. E-3 through E-7
4. E-3 through E-9

1-18. The Commanding Officer may advance what percentage of graduates of recruit training?

1. 10%
2. 15%
3. 20%
4. 25%

1-19. How much obligated service is required for advancements to E-7 through E-9?

1. 18 mos
2. 2 yrs
3. 30 mos
4. 3 yrs

1-20. Candidates for which rates must demonstrate knowledge of military subjects by passing a locally administered military/leadership examination based on naval standards?

1. POs 1&C
2. POs 2&1
3. POs 3 through C
4. POs 3&2

1-21. If the number of vacancies in a rate is more than the number of qualified personnel, what will happen?

1. The best qualified will be advanced
2. Length of service requirements will be waived
3. Time in rate requirements will be waived
4. Those qualified will be advanced

1-22. What are the areas in which personnel seeking advancement are given credit?

1. Seniority, age, and performance
2. Present duty, age, and performance
3. Performance, knowledge, and seniority
4. Scope of duties, education, and performance

1-23. How many factors go to make up the final multiple score?

1. Five
2. Two
3. Three
4. Four

1-24. Advancement authorizations are issued by NAVEDTRAPRODEVCEN for personnel being advanced to paygrades

1. E-3 through E-7
2. E-4 through E-7
3. E-4 through E-6
4. E-3 through E-6

1-25. What does the advancement system guarantee?

1. A certain percentage of personnel in all ratings will be advanced
2. Certain personnel will be advanced
3. All persons within a rating will compete equally
4. Personnel with the highest exam scores will be advanced

1-26. Who schedules the military leadership examinations?

1. Chief of Naval Personnel
2. Commanding Officer
3. Division Officer
4. Education Services Officer

1-27. To find the required and recommended training courses to study for advancement in rating, what publication should you study?

1. Navy Enlisted Manpower and Personnel Classifications and Occupational Standards, NAVPERS 18068
2. Bibliography for Advancement Study, NAVEDTRA 10052
3. Guide for Enlisted Classification
4. Shipboard Training Manual

1-28. Where are (a) Naval Standards and (b) Occupational Standards found in NAVPERS 18068?

1. (a) Section I (b) Section II
2. (a) Section II (b) Section I
3. (a) Section I (b) Section I
4. (a) Section II (b) Section II

1-29. How do you get hold of your copy of the Exam Information Sheet?

1. Request it from the proctor
2. Get it from the Education Services Officer
3. Go to the personnel office for it
4. It will be turned over to you when you turn in your exam

1-30. Your Profile Form Information Sheet helps you identify your strong and weak areas in an examination.

1-31. How do you get copies of the standards and bibliography sheet for your rating?

1. Check with the personnel officer
2. See your division officer
3. Consult the exam proctor
4. Contact your ESO

1-32. What paygrades, if any, are exempted from the Personnel Advancement Requirement (PAR) program?

1. E-3 apprenticeships, E-8, and E-9
2. E-8 and E-9 only
3. E-3 apprenticeships only
4. None

1-33. Which of the following documents replaces the Record of Practical Factors?

1. Personnel Qualifications Standards
2. Engineering Operations Sequencing System
3. Personnel Advancement Requirement (PAR) Program
4. Occupational Standards

1-34. The PAR is made up of how many sections?

1. One
2. Two
3. Three
4. Four

1-35. Why are E-3's exempt from the PAR program?

1. The Navy has other ways of examining them
2. The apprenticeships are too broad
3. The population of E-3's is too large
4. They work with the equivalent of PAR's in "A" school

1-36. What information is found in Section II of the PAR?

1. Formal School and Training Requirements
2. Administration Requirements
3. Occupational Requirements
4. Military Ability Requirements

1-37. Successful completion of the E-4/E-5 military/leadership exam is entered in which section of the PAR?

1. I
2. II
3. III
4. IV

1-38. Which of the following functions is NOT served by the Personnel Qualifications Standards?

1. Describing the knowledge and skills a trainee must have to perform duties correctly
2. Providing a petty officer to teach the learner in each step of work
3. Individualizing learning
4. Placing responsibility for learning on the learner

1-39. Which of these PQS series numbers is incorrectly matched with its title?

1. 100 series -- Theory
2. 200 series -- Purposes
3. 300 series -- Watchstanding
4. 400 series -- Qualification Cards

1-40. Personnel Qualifications Standards support the advancement in rating requirements which are given in the

1. Basic Military Requirements, NAVTRA 10054-D
2. Bibliography for Advancement Study, NAVEDTRA 10052 series
3. Navy Enlisted Manpower and Personnel Classifications and Occupational Standards, NAVPERS 18068 series
4. Personnel Advancement Requirement (PAR) Program, NAVPERS 1414/4

1-41. Which subject section is NOT contained in the Personnel Qualification Standards?

1. 100 series - Theory
2. 300 series - Watchstanding
3. Feedback forms
4. Maintenance

Learning Objective: Identify the purposes, benefits, and limitations of the Planned Maintenance System. Textbook page 1-10.

1-42. Which of the following is NOT a purpose of the Planned Maintenance System?

1. To describe the methods and tools to be used
2. To plan and schedule maintenance tasks
3. To provide increased readiness of the ship
4. To define the maximum planned maintenance required to schedule and control PMS performance

1-43. The Planned Maintenance System (PMS) does NOT include which of the following functions?

1. Administering examinations on maintenance theory
2. Providing for detection and prevention of impending casualties
3. Describing methods and tools to be used
4. Estimating and evaluating material readiness

1-44. Which of the following is NOT a benefit of PMS?

1. Intensified reliability
2. Increased economy
3. Better records
4. Eliminates major corrective maintenance

1-45. The flexibility of the PMS system allows for changes to employment schedules.

1-46. Which of the following actions is NOT required for the Planned Maintenance System to be successful?

1. Professional guidance from several available sources
2. Obtaining a degree in management
3. Direction at each echelon of the organization
4. Training in the maintenance steps and in the system

Learning Objective: Indicate studying techniques and other sources of information needed to prepare for examination. Textbook pages 1-10 through 1-12.

1-47. In studying for advancement, which of the following publications will be a hinderance?

1. NAVSEA Journal
2. Blueprint Reading and Sketching
3. Naval Ship's Technical Manual
4. Obsolete rate training manuals

● If extensive changes in standards occur between annual revisions of NAVEDTRA 10052, a supplementary list of study material will be published in Training Information Procedures for ESO's (TIPS) NAVEDTRA 38016. This publication of the Naval Education and Training Program Development Center is published quarterly to provide a current list of NAVEDTRA publications and other information to update training materials.

1-48. If extensive changes in the Occupational Standards for your rating require an updating of the Bibliography for Advancement Study, where will this revised reading list be published?

1. Naval Sea Systems Notices
2. TIPS
3. The NAVEDTRA monthly magazine
4. The NAVPERS monthly magazine

1-49. How often is NAVEDTRA 10052 revised?

1. Every 6 months
2. Every year
3. Every quarter
4. Every 2 years

1-50. If you are working for advancement to second class, you need to study only the material listed at the second class level.

1-51. Once you have a copy of NAVEDTRA 10052 in hand, the first thing you should do in preparing for advancement is to

1. check the table of contents
2. make sure you have the current edition
3. zero in on the standards that apply to your rating
4. review the standards at lower paygrades

1-52. Which of the courses listed in NAVEDTRA 10052 for your rating must you complete to be eligible to take the advancement in rating examinations?

1. All courses listed for the occupational field 4
2. All courses listed for the next higher rate
3. Courses marked with an asterisk at the next higher rate
4. Unmarked courses listed for the next higher rate

1-53. Each mandatory manual listed in NAVEDTRA 10052 may be completed in one of how many ways?

1. Five
2. Two
3. Three
4. Four

1-54. You are preparing to take the examination for OM2. Which courses and references in NAVEDTRA 10052 will you be examined on?

1. All courses and references listed for E-4 and E-5 for the OM rating
2. All courses listed for E-5 ship maintenance group ratings
3. Courses marked with an asterisk for E-5 and E-6 in the OM rating
4. Courses marked with an asterisk for E-5 group 4 ratings

1-55. How many types of rate training manuals are there?

1. One
2. Two
3. Three
4. Four

In Items 1-56 through 1-58, select the publication from column B that is a source of the information in column A

A. Information

1-56. Knowledge and skills applicable to each paygrade within the OM rating

1-57. Latest edition of a given Rate Training Manual

1-58. References used for source material for advancement examinations

B. NAVEDTRA Publications

1. Navy Enlisted Manpower and Personnel Classifications and Occupational Standards
2. Bibliography for Advancement Study, NAVEDTRA 10052 series
3. List of Training Manuals and Correspondence Course, NAVEDTRA 10061 series
4. The Metric System, NAVEDTRA 475-01-00-75-1

1-59. Each rate training manual contains information relating directly to the occupational qualifications of several ratings.

1-60. Which of the following hints for studying should help you get the most from your Navy training course?

1. Devote your time exclusively to important military topics
2. Try not to cover a complete unit in any one study period
3. Omit easy material; study only the most difficult and the unfamiliar
4. Make notes as you study, putting the main ideas in your own words; then review your notes

1-61. As you study a Navy training course, what study practice should you follow?

1. Set up a fixed number of pages to study in each and every study period
2. Tie in new information with things you know already
3. Memorize as much as you can from a chapter and repeat it to a shipmate
4. Skip over the illustrations and save them until the end of your course

---

Learning Objective: Identify originators of the various theories of light and the characteristics and sources of light. Textbook pages 2-1 through 2-2.

1-62. What theory of light was believed by the ancient Greeks?

1. Generated particles
2. Absolute infraction
3. Expostulating hyperthermia
4. Positive-negative photon

1-63. Newton's corpuscular theory described light as a

1. stream of particles
2. wave of energy
3. reflected energy
4. wave motion

1-64. The wave motion theory of the reflection and refraction of light was developed by

1. Newton
2. Thomas
3. Huygens
4. Fresnel

1-65. Particle supporters believed that light was a wave phenomenon.

1-66. One of the primary arguments which supported the particle theory of light was that

1. light was a wave phenomenon
2. sound can be heard around the corner of a building
3. light travels in a straight line
4. waves created on water cause a disturbance around an obstacle

1-67. Huygens could not explain how light moves through

1. water
2. earth
3. obstacles
4. space

1-68. Which of these concepts was most foreign to Huygen's theory of light?

1. Corpuscles
2. Elastic medium
3. Ether
4. Waves

1-69. In the electromagnetic theory, what did Maxwell's theory hold?

1. Energy was given off intermittently by a radiating body
2. Light was waves of energy transmitted by an electric medium called ether
3. Energy was given off continuously by a radiating body
4. Alternating electric currents with short wavelengths are of electromagnetic origin

1-70. In rejecting the electromagnetic theory, Planck proposed all EXCEPT which of the following ideas?

1. A radiating body contains a large number of tiny oscillators
2. The higher the temperature of the radiating body, the shorter the wavelengths of most energetic radiation
3. Energy from a radiating body is given off continuously
4. Electrical action within the body is due to atoms within the body

1-71. In Plank's Quantum Theory, light is defined as

1. small particles of matter emitted from a source and propagated outward in straight lines
2. a train of waves with fronts perpendicular to the paths of light rays propagated from a source
3. energy radiating continuously from a source and propagated outward as electromagnetic waves
4. small particles of energy radiated from a source and propagated outward in waves

1-72. What discovery in Compton's experiments brought the study of the theory of light back again to the corpuscular theory?

1. Lightwaves of different lengths
2. Small particles of radiated energy are grains of energy
3. Quanta set free move from their source in waves
4. Particles of light have momentum and kinetic energy like particles of matter

1-73. What discovery caused many scientists to accept Maxwell's earlier rejected electromagnetic theory?

1. Phenomena of light not accounted for by the wave theory
2. Particles of light with momentum and kinetic energy
3. Lightwaves of different lengths
4. Quanta have frequencies like waves

1-74. What theory of light is used in all discussions in this manual?

1. Quantum
2. Wave
3. Electromagnetic
4. Corpuscular

1-75. Which celestial objects are sources of natural light?

1. Sun and comets
2. Moon, sun, and stars
3. Sun and stars
4. Moon and sun

Assignment 2

The Nature of Light (Continued)

Textbook Assignment: Pages 2-2 through 2-21

Learning Objective: Recognize the characteristics of light, illumination, and radiation. Textbook pages 2-1 through 2-5.

2-1. Which of these sources of light is considered "natural" in the study of optics?

1. Volcanic activity
2. Insect luminescence
3. Stars
4. Lightning

2-2. Which of the following examples is an artificial source of light?

1. Lightning
2. Vegetable luminescence
3. Fluorescent light
4. Volcanic activity

2-3. Any object that can be seen due to light energy reflected from its surface is called a/an

1. illuminated body
2. luminous body
3. absorbent body
4. radiant body

2-4. Illumination means the act of

1. casting light energy
2. receiving light energy
3. holding light energy
4. creating light energy

2-5. Which of the following meters is used to measure the intensity of illumination?

1. Electrician's multimeter
2. Photographer's exposure meter
3. Alpha meter Mk 10
4. Pocket dosimeter IM 9

2-6. The illumination on a table top at right angles to and at a fixed distance from a point source is measured in units of

1. watts
2. candles
3. foot-candles
4. intensity

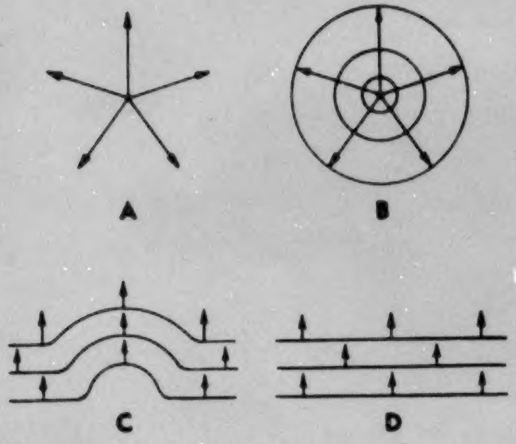
2-7. What is the degree of illumination on a surface 20 feet directly below a point source compared to the degree of illumination on a surface 2 feet directly above the same source?

1. 1/10 as great
2. 1/20 as great
3. 1/40 as great
4. 1/100 as great

2-8. If the plane in figure 2-2 of the text is 3 feet from the light source, the illumination is

1. 1 foot-candle
2. 1/3 foot-candle
3. 3 foot-candles
4. 1/9 foot-candle

413



1,379

Figure 2A

2-9. Which part of figure 2A best depicts light energy traveling outward from a point source?

1. A
2. B
3. C
4. D

2-10. What is thermal radiation?

1. Mechanical electromagnetic waves
2. Energy in the form of wave motion
3. Heat
4. The same as light energy

Learning Objective: Identify the characteristics of light transmission, its uses, and solve conversion problems. Textbook pages 2-5 through 2-11.

2-11. What is the main purpose of optical instruments?

1. Image formation
2. Light reflection
3. Light refraction
4. Light absorption

2-12. How far do wave fronts move from a source of light before they are considered to be parallel to each other?

1. 1,000 yd
2. 1,500 yd
3. 2,000 yd
4. 2,500 yd

2-13. A pinhole camera takes a picture of a T-shaped object. The image formed on the film in the camera looks like

1. ⊤
2. ⊥
3. ⊣
4. ⊢

2-14. If waves are moving at a speed of 4 feet per second and have a frequency of 12 waves per second, what is the wavelength?

1. 0.33 ft
2. 0.50 ft
3. 0.66 ft
4. 0.75 ft

2-15. About how many millimeters are in an inch?

1. 39
2. 25
3. 14
4. 8

2-16. A millimeter contains how many microns?

1. 10
2. 100
3. 1,000
4. 10,000

2-17. How many millimicrons are in a micron?

1. 10
2. 100
3. 1,000
4. 10,000

2-18. How many angstroms are in a millimicron?

1. 10
2. 100
3. 1,000
4. 10,000

2-19. How many X-rays units are in an angstrom unit?

1. 10
2. 100
3. 1,000
4. 10,000

2-20. The regions of the electromagnetic spectrum immediately surrounding visible light are

1. radar and gamma
2. radio and infrared
3. cosmic and radio
4. infrared and ultraviolet

2-21. The visible portion of the electromagnetic spectrum consists of wavelengths from

1. 0.000015 to 0.000026 inch
2. 0.000015 to 0.000038 inch
3. 0.000038 to 0.000066 inch
4. 0.000026 to 0.000066 inch

2-22. Wavelengths that we use to see by are between

1. 200 and 300 mμ
2. 300 and 500 mμ
3. 400 and 600 mμ
4. 400 and 700 mμ

2-23. Which of these colors has the shortest wavelength?

1. Indigo
2. Green
3. Orange
4. Red

2-24. Which of these colors has the longest wavelength?

1. Violet
2. Blue
3. Green
4. Orange

2-25. What kind of rays are given off by atomic particles?

1. Alpha
2. Beta
3. Gamma
4. Delta

2-26. Sunburn comes from which type of rays?

1. X-ray
2. Cosmic
3. Gamma
4. Ultraviolet

2-27. What part of the electromagnetic spectrum is used for confidential signalling between ships at night?

1. Radio
2. TV
3. Ultraviolet
4. Infrared

2-28. What is the principle upon which a Snooperscope or Sniperscope works?

1. Gamma rays are directed at an object and reflected back to a device which changes the reflected rays to X-rays and then to visible light
2. Infrared light is directed at an object and reflected back to a device which changes the reflected light to visible wavelengths
3. Infrared light of a given wavelength is directed at an object and reflected back to a device which detects any change in the wavelength of the reflected light
4. Radar waves are directed at an object and reflected back to the wave source where the reflected waves are changed to visible light

2-29. How long does it take for radar to reach the moon?

1. 1.0 sec
2. 1.3 sec
3. 2.0 sec
4. 2.6 sec

2-30. What accounts for the bending of light rays?

1. The length of waves in the electromagnetic spectrum
2. The difference of heat in the media through which light travels
3. The difference in the speed of light through different media
4. The different laws of optics

2-31. What difficulty prevented Roemer from finding the exact speed of light?

1. He thought that the speed of light was instantaneous
2. He could not accurately calculate when one of the moons would be eclipsed by Jupiter
3. He calculated a 1,200-second delay instead of a 1,000-second delay in the predicted time of eclipse
4. He tried to calculate too far ahead

2-32. Which, if any, of the following items did Professor Michelson use to measure the speed of light?

1. A round mirror mounted on top of one mountain reflecting a ray of light to a photoelectric sensing device located 20 miles away
2. An octagonal mirror located on top of a mountain reflecting a ray of light to another mirror located on another mountain 20 miles away
3. An octagonal mirror, lenses, and light source mounted on top of one mountain and a concave and plane mirror located on top of another mountain 22 miles away
4. None of the above

2-33. The speed of light is fastest in

1. air
2. ordinary crown glass
3. water
4. medium flint glass

2-34. Of the media given, the speed of yellow light is slowest in

1. rock salt
2. quartz
3. carbon disulfide
4. diamond

2-35. What, if anything, happens to the speed of light as it travels from air into water?

1. Increases
2. Decreases
3. Increased and then decreased
4. Nothing; it remains unchanged

Learning Objective: Identify characteristics of light which determine its variations of color. Textbook pages 2-11 and 2-12.

2-36. The process of breaking white light into its colors is called

1. dispersion
2. fragmentation
3. reflection
4. refraction

2-37. Why do you see red when you look at a piece of red paper in the sunlight?

1. The paper is absorbing a lot of red
2. The paper is reflecting a lot of red
3. The paper is dispersing a lot of red
4. The paper is refracting a lot of red

2-38. Why do some of the stripes in our national flag appear as red stripes when light strikes them?

1. They reflect all colors except red
2. They reflect red light only
3. They absorb red light only
4. They absorb all colors with wavelengths smaller than the wavelength of red light

2-39. When you look through a yellow glass, you see yellow because the glass is

1. reflecting yellow
2. dispersing yellow
3. refracting yellow
4. transmitting yellow

2-40. Usually, yellow glass transmits which of the following other colors?

1. Red
2. Violet
3. Blue
4. Green

2-41. If yellow, red, orange, and a little green enter your eye at once, what color(s) will you see?

1. A mixture
2. Yellow
3. Orange
4. Green

2-42. Which of these colors are mainly responsible for making haze visible?

1. Red and orange
2. Red and violet
3. Blue and violet
4. Yellow and red

Learning Objective: Determine how light is affected as it passes through various media. Textbook pages 2-13 and 2-14.

2-43. What type of light enables us to see things?

1. Refracted
2. Reflected
3. Absorbed
4. Dispersed

2-44. What are the three classes of objects according to the action of light as it falls upon them?

1. Opaque, translucent, and transparent
2. Refracted, diffracted, and dispersed
3. Diffused, subfused, and obfused
4. Refracting, reflecting, and transmitting

2-45. Tubes that hold lenses and prisms in optical systems to prevent entrance of light are classified as

1. opaque
2. translucent
3. transparent
4. textured

2-46. If all the light that falls on an object is either reflected or absorbed, that object is said to be

1. transparent
2. translucent
3. opaque
4. textured

2-47. When light falls upon a translucent object, how much light, if any, is transmitted through it?

1. Most of the light
2. Very little
3. Almost half
4. None

2-48. What occurs if a piece of rough textured stained glass is placed between a light source and the viewer?

1. Very little light passes through the glass, and the light source is barely visible
2. Much of the light passes through the glass, and the light source can be seen clearly
3. Much light passes through, but a clear image of the light cannot be seen
4. Very little light passes through the glass, and the light source is not visible

2-49. Reflection and absorption are prime factors in determining the quality of which type of glass?

1. Window
2. Optical
3. Tempered
4. Silvered

In items 2-50 through 2-53, select the type of object from column B that matches the description listed in column A.

	A. Description	B. Type of object
2-50.	An object that absorbs or reflects all light which falls upon it	1. Opaque 2. Translucent 3. Transparent
2-51.	An object that returns a light beam back at the same angle as the incoming beam	4. Reflecting
2-52.	An object that permits most light rays to pass through it	
2-53.	An object that causes light to be diffused or scattered in all directions	

● In textbook figure 2-22, the spacing between the parallel wave fronts is an indication of the speed of light as light passes through a transparent medium or from one medium to another. When light travels in a medium of constant optical density or between media of equal optical density, its speed is constant and is indicated by equal spacing of wave fronts; when light passes from one medium into another of different optical density, its speed changes and the change is indicated by either wider or narrower spacing of the wave fronts--wider for increase in speed and narrower for decrease in speed.

Refer to figure 2B and the preceding information in answering item 2-54.

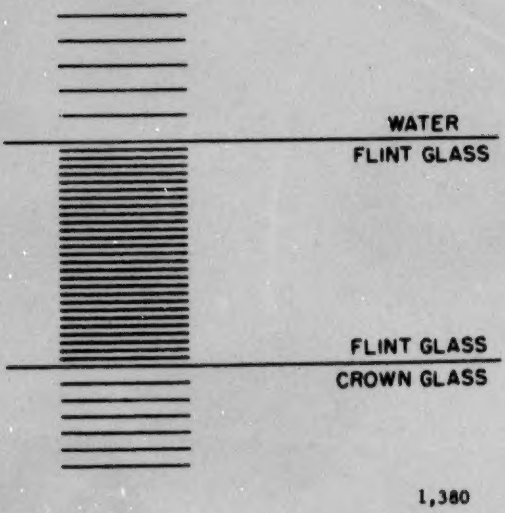


Figure 2B

2-54. What can you infer about the speed of light through water, flint glass, and crown glass?

1. Light travels faster through water than through either flint glass or crown glass
2. Light travels faster through flint glass than through either water or crown glass
3. Light travels faster through flint glass than through crown glass
4. Light travels faster through crown glass than through water

---

Learning Objective: Identify the laws of reflection and refraction. Textbook pages 2-14 through 2-21.

● Refer to figure 2-17 of the textbook to answer items 2-55 and 2-56.

2-55. If you shift a mirror to any angle from its perpendicular position, what, if anything, happens to the reflected beam?

1. It is shifted at an angle from the incoming beam three times as great as the angle by which you shifted the mirror
2. It is shifted at an angle from the incoming beam half as great as the angle by which you shifted the mirror
3. It is shifted at an angle from the incoming beam twice as great as the angle by which you shifted the mirror
4. It is not changed, but it is reflected back along its beams

2-56. If you shift a mirror 30° from a perpendicular incoming beam, the reflected beam is projected at what angle to the incoming beam?

1. 40°
2. 50°
3. 60°
4. 70°

2-57. A line drawn perpendicular to a flat reflecting surface in the same plane and at the point where a beam of light strikes the surface represents the

1. incident ray
2. reflected ray
3. normal to the surface
4. normal to the path of the reflected ray

2-58. The angle formed by an incident ray and its reflected ray is equal to the

1. angle of incidence
2. angle of reflection
3. average of the angles of incidence and reflection
4. sum of the angles of incidence and reflection

2-59. If a beam of light is reflected from a flat mirror at an angle of 23° to the normal, the angle of incidence is

1. 0°
2. 11 1/2°
3. 23°
4. 46°

2-60. In figure 2-19 of the text, if angle a is 30°, then angle b must be

1. 15°
2. 22 1/2°
3. 30°
4. 45°

2-61. Suppose that sunlight is being reflected from a flat irregular surface. Which of the following conditions exists?

1. Light rays incident to the surface are not parallel
2. Light rays reflected from the surface are not parallel
3. Light rays reflected from the surface converge at a point on the normal
4. Light rays incident to the surface converge at a point on the normal

2-62. A ray of light can pass from air into glass without being refracted if the angle of incidence is

1. 0°
2. 45°
3. between 45° and 90°
4. 90°

2-63. When a wave front of light angles from air into a sheet of plate glass, why does the path of the wave front pivot toward the normal?

1. The last edge of the wave front to enter the glass decreases in speed while the first edge increases in speed
2. The last edge of the wave front to enter the glass increases in speed
3. The first edge of the wave front to enter the glass decreases in speed
4. The first edge of the wave front to enter the glass increases in speed

2-64. In part B of figure 2-22 in your textbook, assume that the wave front enters the glass at a 30° angle and that the surfaces of the glass plate are parallel. What is the angle at which the front emerges from the glass?

1. 15°
2. 30°
3. 45°
4. 60°

2-65. What angle in figure 2C is designated as the angle of refraction?

1. C
2. D
3. E
4. F

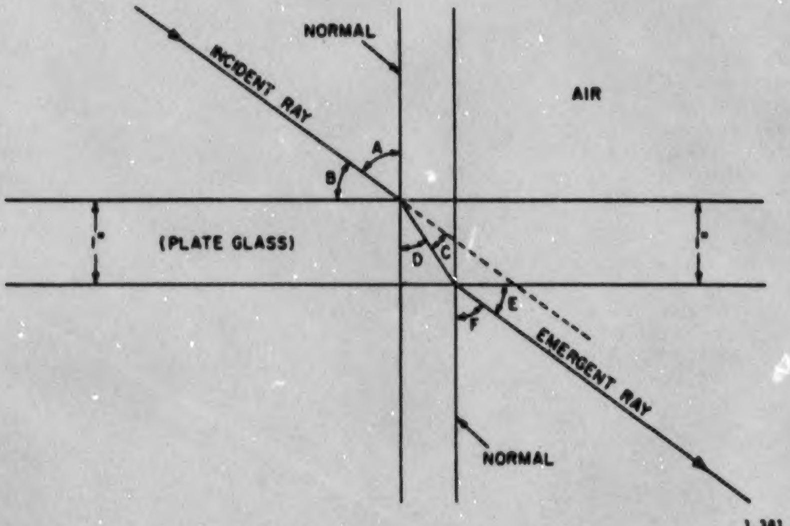


Figure 2C

2-66. What angles in figure 2C are necessarily equal?

1. A and F
2. A and E
3. C and E
4. C and D

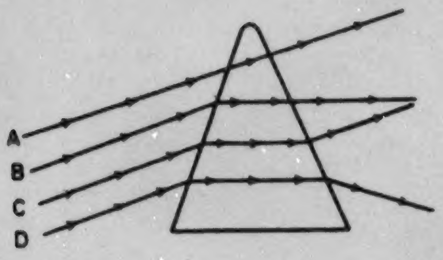


Figure 2D

2-67. Four light rays are shown passing through the triangular prism of figure 2D. Which ray is shown correctly?

1. A
2. B
3. C
4. D

2-68. In a prism, the angle of deviation is measured between the emergent ray and which ray or normal?

1. Incident ray
2. Refracted ray
3. Emergent normal
4. Incident normal

2-69. The index of refraction for a medium is the ratio between the speed of light in a vacuum and the speed of light in a/an

1. transparent medium
2. translucent medium
3. opaque medium
4. diffracted medium

2-70. In optical drawings the index of refraction is indicated by the letter

1. n
2. o
3. p
4. s

2-71. The absolute indexes of refraction are considered to be the same for

1. air and vacuum
2. vacuum and water
3. water and air
4. fused quartz and crown glass

2-72. What is the approximate index of refraction of a transparent medium if the speed of light through the medium is 75,000 miles per second?

1. 1.25
2. 1.29
3. 2.13
4. 2.50

2-73. In the formula for Snell's law, what does n' mean?

1. Index of refraction of the first medium
2. Index of refraction of the second medium
3. Angle of incidence
4. Angle of refraction

2-74. When measuring the angle of incidence, what are your two references?

1. Incident ray and refracted ray
2. Refracted ray and normal
3. Incident ray and normal
4. Emergent ray and normal

2-75. In figure 2-23 of the text, when the light ray is reversed through the medium, what will be the new designation of the original refracted ray?

1. Emergent ray
2. Refracted ray
3. Incident ray
4. Normal

Assignment 3

The Nature of Light (Continued); Mirrors and Prisms

Textbook Assignment: Pages 2-23 through 3-16

Learning Objective: Solve problems involving refraction of light. Textbook pages 2-23 through 2-27.

3-1. In figure 2-32 of the text, when you reach the critical angle and the ray is refracted along the surface, what is the angle of refraction to the normal?

1. 22 1/2°
2. 30°
3. 45°
4. 90°

3-2. At which angle is a 30° incident ray refracted on entering a flat surface of water from air?

1. 12°
2. 22°
3. 32°
4. 42°

3-3. At approximately what angle of incidence does a beam of light strike the interface between air and light flint glass if the angle of refraction produced is equal to 16°?

1. 14°
2. 16°
3. 23°
4. 26°

In Items 3-4 through 3-7, match the substance in column A with the critical angle in column B. The external medium is air.

	A. Substance	B. Critical Angle
3-4.	Water	1. 48°36'
3-5.	Quartz	2. 41°18'
3-6.	Diamond	3. 40°22'
3-7.	Crown glass	4. 24°26'

3-8. What makes the sun visible below the horizon?

1. Light rays in cooler air
2. Less dense air toward the surface of the earth
3. The refractive index of the surface of the atmosphere
4. The bending of light through the atmosphere

3-9. What atmospheric phenomenon is the opposite of a mirage?

1. Rainbow
2. Heat wave
3. Looming
4. Reflection and dispersion combined

3-10. At which of these times is it easiest to see a rainbow?

1. 1600
2. 1300
3. 1200
4. 1100

Learning Objective: Recognize basic principles and methods of using metric, English, Navy mil, and degree systems for optical measurements. Textbook pages 3-1 through 3-3.

3-11. The Opticalman uses all EXCEPT which of the following systems of measurements?

1. Troy system
2. Metric system
3. Mil system
4. Degree system

3-12. What factor makes the English system of measurement hard to use?

1. Lack of decimals
2. Lack of simple relationships between units
3. No metric equivalent
4. No acceptance universally

In Items 3-13 through 3-16, select from column B the abbreviation for the unit of measurement in column A.

	A. Unit of measurement	B. Abbreviation
3-13.	Temperature	1. cd
3-14.	Luminous Intensity	2. k
3-15.	Time	3. K
3-16.	Mass	4. s

3-17. What is the basic metric unit of measurement for length?

1. Centimeter
2. Millimeter
3. Meter
4. Kilometer

3-18. Which of the following is the most commonly used metric unit of measurement for mass?

1. Cubic centimeter
2. Centigram
3. Decagram
4. Kilogram

3-19. The diameter and focal length of lenses are usually stated in

1. millimeters
2. centimeters
3. inches
4. tenths of inches

3-20. What is a quick and easy way to determine how many millimeters equal 81.9 decimeters?

1. Multiply by 10
2. Divide by 10
3. Move the decimal point two digits to the right
4. Move the decimal point one digit to the left

3-21. The basic conversion factor in the metric system consists of

1. fractions
2. integers
3. decimals
4. roots

3-22. How many conversion factors does the metric system have?

1. One
2. Two
3. Three
4. Four

3-23. Which one of the following lengths is NOT equal to the other three?

1. 6 meters
2. 60 decimeters
3. 60 millimeters
4. 600 centimeters

3-24. Which of the following measures is/are the equivalent of ten thousand millimeters?

1. 1 dekameter
2. 10 meters
3. 100 decimeters
4. All of the above

3-25. An example of a Greek prefix is

1. deci
2. micro
3. kilo
4. milli

3-26. An example of a Latin prefix is

1. deka
2. hecto
3. mega
4. centi

3-27. How many kilometers are in 50 yards?

1. 0.0045 km
2. 0.045 km
3. 0.45 km
4. 4.5 km

3-28. How many yards are in 50 meters?

1. 45 yd
2. 54 yd
3. 61 yd
4. 64 yd

3-29. How many millimeters are in 3/4 inch?

1. 0.029 mm
2. 2.95 mm
3. 19.05 mm
4. 33.80 mm

3-30. How many inches are in 35 millimeters?

1. 1.02 in.
2. 1.38 in.
3. 1.94
4. 2.03

3-31. How many yards are in 42 1/2 meters?

1. 38 yd
2. 42 yd
3. 46 yd
4. 48 yd

3-32. A liter is the volume of a cube that measures how many inches on each side?

1. 39.37 in.
2. 3.937 in.
3. 0.3937 in.
4. 0.03937 in.

3-33. How many liters are in a gallon?

1. 3.784 liters
2. 1.057 liters
3. 37.84 liters
4. 10.57 liters

3-34. If a quart of milk costs 50 cents, a liter costs

1. 47 cents
2. 53 cents
3. 56 cents
4. 60 cents

3-35. One gram equals the weight of water contained in 1 cubic

1. decimeter
2. centimeter
3. micrometer
4. millimeter

3-36. Meter, liter, and gram are abbreviated respectively as

1. mm, l, and g
2. m, l, and g
3. m, ml, and g
4. m, l, and mg

3-37. How many minutes are in 90°?

1. 60
2. 360
3. 540
4. 5400

3-38. How many mils make a circumference?

1. 360
2. 3600
3. 640
4. 6400

3-39. If an object 5,000 meters distant produces a visual angle of 1 mil, how long is that object?

1. 1 meter
2. 5 meters
3. 10 meters
4. 50 meters

Learning Objective: Point out characteristics of images and the effects prisms and mirrors have on them. Textbook pages 3-3 through 3-15.

3-40. What are the types of images?

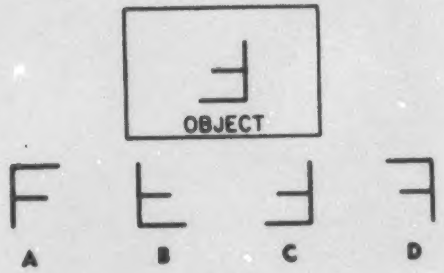
1. Real and virtual
2. Synthetic and virtual
3. Unreal and real
4. Unreal and virtual

3-41. An image that cannot be formed on a screen is called a

1. false image
2. virtual image
3. reverted image
4. real image

3-42. What type of image can be reproduced by film?

1. False
2. Virtual
3. Reverted
4. Real



1,383

Figure 3A

3-43 Which of the images in figure 3A is a normal, inverted image of the object illustrated?

1. A
2. B
3. C
4. D

3-44. An image formed by a plane mirror is described as

1. real, virtual, and erect
2. virtual, inverted, and reverted
3. reverted, erect, and virtual
4. erect, reverted, and real

3-45. According to figure 3-6 in the text, where should you stand to describe an image of an object formed by a lens?

1. Between the optical element and the image, looking at the image
2. Between the optical element and the object, looking at the object
3. Behind the optical element, looking at the image
4. Behind the optical element, looking at the object

3-46. A mirror with a smooth, flat surface changes the direction of light by

1. refraction
2. refraction and reflection
3. reflection
4. refraction or reflection

3-47. Which of the following is NOT a function of mirrors?

1. Produce images
2. Alter the path of light
3. Alter the attitude of objects
4. Transmit light from an object to the point desired

3-48. What is the attitude of the F in the apparent position of the object in figure 3-8 of the text?

1. Erect and reverted
2. Erect and inverted
3. Normal and inverted
4. Normal and reverted

3-49. How many degrees is an object reflected if two mirrors are placed at right angles?

1. 360°
2. 180°
3. 90°
4. 45°

3-50. In figure 3-9 of the text, if you stood between the mirrors and the object, what attitude would the object assume?

1. Erect and normal
2. Normal and inverted
3. Inverted and reverted
4. Reverted and normal

3-51. Which of the following is/are an advantage of prisms over silvered mirrors?

1. Prisms are not easily disturbed
2. Prisms can produce more numerous reflecting paths
3. Prisms are not affected by old age
4. All of the above

3-52. At least how many surfaces of a prism are NOT parallel?

1. One
2. Two
3. Three
4. Four

3-53. Prisms are generally made from

1. borosilicate crown glass
2. plain crown glass
3. silicate crown glass
4. monosilicate crown glass

3-54. What kind of surfaces do prisms have?

1. Plane
2. Convex
3. Concave
4. Plano-convex

3-55. Optical wedges direct light by

1. reflection
2. refraction
3. reflection and refraction
4. either reflection or refraction

3-56. Which prism is used when the angle of deviation is a matter of fractions of seconds?

1. Porro
2. Penta
3. Rhomboid
4. Optical wedge

3-57. The dioptric strength of a prism is the distance 1 meter away from the prism between the

1. reflected and refracted rays
2. reflected and incident rays
3. incident and refracted rays
4. incident and deviated rays

3-58. If the deviation of the light passing through a prism is 3 cm at 1 meter from the prism, the dioptric strength of the prism is

1. 0.33
2. 0.67
3. 3
4. 6

3-59. Most of the prisms in optical systems are of what type?

1. Reflecting
2. Refracting
3. Deviating
4. Compensating

3-60. A four-diopter prism at a distance of 1/2 meter will deviate the path of light

1. 0.5 cm
2. 2 cm
3. 8 cm
4. 4 cm

3-61. If a right-angle prism is rigidly mounted and only rays of light parallel to the normal on a side opposite the hypotenuse are permitted to enter, the rays are reflected at a true angle of

1. 45°
2. 90°
3. 135°
4. 180°

3-62. If a silvered right-angled prism is used to elevate the line of sight 84°, how much should the prism be tilted?

1. 21°
2. 42°
3. 84°
4. 168°

3-63. Some right-angled prisms have their reflecting surfaces silvered to

1. make usable all light that strikes the reflecting surface
2. reduce glare and light intensities
3. decrease the amount of light entering the prism
4. reduce absorption and increase refraction

3-64. Which prism is a right-angle prism used to bend a beam of light through 180°?

1. Dove
2. Porro
3. Penta
4. Rhomboid

3-65. An object viewed through a porro prism cluster has an attitude that is

1. inverted and reverted
2. inverted and erect
3. reverted and erect
4. normal and erect

3-66. What is the attitude of an object viewed through a dove prism?

1. Inverted
2. Reverted
3. Either inverted or reverted
4. Inverted, reverted, and normal

3-67. When a dove prism is rotated 90° in either direction, the same object will appear

1. inverted and reverted
2. erect and reverted
3. normal and erect
4. reverted and normal

3-68. Which prism is like a parallelogram?

1. Dove
2. Porro
3. Rhomboid
4. Penta

3-69. Which prism offsets a beam of light without changing the attitude of the object or the direction of the beam?

1. Rhomboid
2. Dove
3. Penta
4. Porro

3-70. Which prisms do NOT have silvered reflecting surfaces?

1. Rhomboid
2. Porro
3. Penta
4. Dove

3-71. Which type of prism can be used to bend a beam of light through 90° without changing the attitude of the object?

1. Right-angle
2. Penta
3. Dove
4. Porro

3-72. If the angle between the reflecting surfaces of a penta prism is 30°, the deviation will be

1. 30°
2. 37 1/2°
3. 45°
4. 60°

3-73. When a penta prism is held so that reflection takes place in the horizontal or vertical plane, all objects viewed will assume what attitude?

1. Normal and erect
2. Normal and reverted
3. Inverted and erect
4. Inverted and reverted

3-74. In figure 3-19A of the text, light reflected from the roof edge in this manner will cause objects to appear

1. normal and erect
2. inverted and erect
3. inverted and reverted
4. reverted and normal

3-75. What angle does an Amici prism reflect?

1. 45°
2. 60°
3. 90°
4. 135°

Assignment 4

Lenses

Textbook Assignment: Pages 4-1 through 4-19

Learning Objective: Point out the properties of glass. Textbook pages 4-1 and 4-2.

4-1. What optical elements are the most important and the most widely used to control light?

1. Prisms
2. Mirrors
3. Lenses
4. Telescopes

4-2. What is the only common characteristic of all glass?

1. It has a definite shape
2. It has a crystalline form
3. It is transparent
4. It is amorphous

4-3. The physical properties of glass are explainable only if we assume that they all have the same molecular arrangement as a

1. liquid
2. gas
3. solid
4. crystal

4-4. What is devitrification?

1. A transition from a liquid to an amorphous state
2. A change to crystalline structure
3. A double refraction
4. A single refraction

4-5. In a liquid state, glass is a mixture of chemicals in solution, the most common of which are

1. silicates and borates
2. sulfates and nitrates
3. nitrates and borates
4. silicates and nitrates

4-6. Although glass is a liquid, it is also a/an

1. crystal
2. solid
3. gas
4. ether

4-7. The electric field of the atoms of one molecule causes a similar variation in the electric field of the atoms of another molecule to generate attraction between them. This condition is caused by

1. molecular attraction
2. polaric generity
3. Van der Walls forces
4. serendipity

4-8. The bend that developed in the glass tube placed against the bulkhead is part of an experiment to show that glass is

1. of definite shape
2. a solid
3. neither a liquid nor a solid
4. amorphous

Learning Objective: Identify the optical qualities of glass. Textbook pages 4-2 through 4-4.

4-9. What is the most important quality of optical glass?

1. Refraction
2. Freedom from color
3. Transparency
4. Homogeneity

4-10. Veins or striae are defects in the characteristic of glass called

1. heterogeneity
2. homogeneity
3. refraction
4. transparency

4-11. Veins or striae are little streaks in glass which interfere with what quality?

1. Refraction
2. Transparency
3. Dispersion
4. Translucency

4-12. How many bubbles are allowed in the best lenses?

1. One or two
2. Two or three
3. Three or four
4. Four or five

4-13. What limit is placed on the size of a bubble for glass to be used in precision lenses?

1. 1 mm
2. 1/2 mm
3. 1 cm
4. 1/2 cm

4-14. The degree of absorption of light in a given piece of glass can be changed by varying the

1. number of bubbles in the glass
2. size of the bubbles in the glass
3. color of the light
4. color of the glass

4-15. The bending of a light ray when it enters a lens or prism defines

1. dispersion
2. diffraction
3. refraction
4. abstraction

4-16. The separation of light into its component colors as it passes through a prism or lens is the definition of

1. abstraction
2. refraction
3. diffraction
4. dispersion

4-17. Condensed moisture on glass absorbs carbon dioxide and forms

1. carbon monoxide
2. sulfuric acid
3. hydrochloric acid
4. carbonic acid

4-18. Strain in glass is caused by

1. improper cleaning
2. inordinate wear
3. improper annealing
4. inordinate polishing

4-19. Which of these types of raw materials appears in optical glass?

1. Stable
2. Volatile
3. Combustible
4. Corrosive

4-20. Crown glass contains no

1. barium
2. lead
3. phosphorus
4. boron

4-21. The more lead used in optical glass the higher the index of

1. diffraction
2. refraction
3. dispersion
4. homogeneity

4-22. Flint glass has a higher index of refraction than does crown glass because flint glass contains

1. phosphorus
2. barium
3. lead
4. boron

4-23. The three physical categories of lenses are

1. thin, thick, and complex
2. simple, complex, and compound
3. thin, simple, and compound
4. thin, thick, and compound

4-24. Which of these lenses is/are a convergent (positive) lens(es)?

1. Plano-convex
2. Plano-concave
3. Double concave
4. All of the above

4-25. Which of these lenses is always a divergent (negative) lens?

1. Plano-concave
2. Plano-convex
3. Convexo-concave
4. Double convex

Learning Objective: Indicate lens terminology by defining terms used in the study of lenses. Textbook pages 4-5 through 4-7.

4-26. Curvature means the amount of departure from a

1. convex surface
2. concave surface
3. flat surface
4. double concave surface

4-27. A line segment extending from the center of a sphere to the curved surface is called the

1. diameter of curvature
2. sphere of influence
3. arc of determination
4. radius of curvature

4-28. The primary factor in determining the refracting ability of a lens is the

1. radius of curvature
2. sphere of influence
3. arc of determination
4. diameter of curvature

4-29. The distance from the principal focus to the optical center is the definition of the

1. radius of curvature
2. focal length
3. focal curvature
4. optical axis

4-30. What is the imaginary straight line passing through the centers of curvature of both surfaces of a lens?

1. Focal length
2. Radius of curvature
3. Optical center
4. Optical axis

4-31. Imaginary planes at the point where the incident ray, if prolonged, would intersect the prolonged emergence ray are called the

1. focal planes
2. radius planes
3. optical axis
4. principal planes

4-32. At what point in a lens do light rays pass without deviation?

1. Optical center
2. Principal focal point
3. Radius of curvature
4. Principal plane

4-33. Where do parallel incident rays converge after they pass through a convergent lens?

1. Optical axis
2. Optical center
3. Principal focal point
4. Principal plane

4-34. How many points of principal focus is/are on one side of a convergent lens?

1. One
2. Two
3. Three
4. Four

4-35. In figure 4-6 of the text, the points of principal focus are

1. 2F and F_1
2. 1F and 2F
3. F_1 and F_2
4. F_1 and 1F

4-36. In figure 4-6 of the text, HI and H'I' are called the

1. principal focal planes
2. principal focal points
3. optical axes
4. optical centers

Learning Objective: Identify the characteristics of positive and negative lenses; and recognize the elements of image formation. Textbook pages 4-7 through 4-13.

4-37. Since a negative lens will not produce a real image, what must you do to establish the imaginary focal length?

1. Extend the emergent rays back through the lens
2. Extend the incident rays back through the lens
3. Extend both the emergent and incident rays back through the lens
4. Bend the emergent and incident rays back toward normal

4-38. What is the source of light ray emanation from an object?

1. From only the divergent points
2. From only the convergent points
3. From all points on the object
4. From all points within the object

4-39. Figure 4-10 of the text shows the real image to be

1. inverted and reverted
2. reverted and augmented
3. inverted and augmented
4. reverted and diminished

4-40. Why does a light ray that passes along the optical axis through a lens NOT bend?

1. It strikes the surfaces of the lens perpendicular to the normal
2. It strikes the surfaces of the lens parallel to the normal
3. It passes through the lens at the normal
4. It passes through the optical center and deviates

4-41. In figure 4-10 of the text, what optical function is at work to produce the image?

1. Diffraction
2. Refraction
3. Homogeneity
4. Heterogeneity

● In answering Items 4-42 through 4-45, refer to figure 4-11 in the text.

4-42. Which ray is NOT refracted?

1. D
2. C
3. B
4. A

4-43. Which ray runs parallel to the optical axis until it strikes the lens?

1. A
2. B
3. C
4. D

4-44. Which ray emerges parallel to the optical axis?

1. A
2. B
3. C
4. D

4-45. Which ray passes through a point two focal lengths in front of the lens?

1. A
2. B
3. C
4. D

4-46. When an object is at infinity, incident rays of light from it are parallel and the image is of what type?

1. Real, inverted, reverted, and diminished
2. Real, erect, reverted, and diminished
3. Real, inverted, reverted, and enlarged
4. Real, erect, reverted, and enlarged

4-47. If an object is at a distance beyond two focal lengths but less than infinity, what type of image is formed between the secondary focal point and 2F on the opposite side of the lens?

1. Real, erect, reverted, and diminished
2. Real, inverted, reverted, and enlarged
3. Real, inverted, reverted, and diminished
4. Real, erect, reverted, and enlarged

4-48. In figure 4-13 of the text, you see an object placed two focal lengths in front of the lens. The image the lens forms of this object is real, inverted, reverted, and

1. twice the size
2. half the size
3. equal in size
4. just less than equal in size

4-49. As you see in figure 4-14 of the text, an object at a distance between one and two focal lengths from a lens produces an object that is real, inverted, reverted, and

1. smaller than the object
2. the same size as the object
3. half the size of the object
4. larger than the object

4-50. When an object is closer to a lens than the principal focus, the rays appear to converge behind the object to produce an image that is

1. erect, normal, enlarged, and virtual
2. real, inverted, reverted, and virtual
3. real, normal, inverted, and reverted
4. erect, normal, virtual, and inverted

4-51. The lens becomes a magnifying glass when the object is between the

1. auxiliary focal point and the lens
2. principal focal point and the lens
3. auxiliary focal point and the image
4. principal focal point and the image

4-52. When a negative lens is in contact with an object, how do you see the image?

1. Erect, normal, virtual, and slightly larger than the object
2. Real, inverted, reverted, and equal in size to the object
3. Real, inverted, reverted, and smaller in size than the object
4. Erect, normal, virtual, and slightly smaller than the object

---

Learning Objective: Recognize the purpose and use of cylindrical lenses and spherical mirrors. Textbook pages 4-14 through 4-17.

4-53. Figure 4-18A of the text shows what type of lens?

1. Positive cylindrical
2. Negative cylindrical
3. Positive spherical
4. Negative spherical

4-54. How many types of cylindrical lenses are there?

1. One
2. Two
3. Three
4. Four

4-55. A positive cylindrical lens converts a point source of light into a

1. wide band of light
2. narrow band of light
3. narrow line of light
4. wide line of light

4-56. A negative cylindrical lens converts a point of light into a

1. narrow band of lesser intensity
2. broad band of greater intensity
3. narrow band of lesser intensity
4. broad band of lesser intensity

4-57. Which of the following types of lens(es) is/are often used in eyeglasses to correct vision defects?

1. Positive and negative cylindrical
2. Positive and negative parabolic
3. Only negative cylindrical
4. Only positive cylindrical

4-58. What type of rearview mirror is used on automobiles and trucks to give the drivers a wide field of vision?

1. Concave
2. Convex
3. Plano-convex
4. Double convex

4-59. What is line CV in figure 4-19 of the text?

1. Arc of a circle
2. Diameter of a circle
3. Circumference of a circle
4. Radius of a circle

4-60. Concave mirrors will form real images by treating the light from the image in what way?

1. Refracting it
2. Diffracting it
3. Reflecting it
4. Redirecting it

4-61. When an object is located beyond the center of curvature of a concave mirror, the image attitudes will be what type?

1. Real, inverted, normal, and enlarged
2. Real, upright, normal, and diminished
3. Real, inverted, reverted, and diminished
4. Real, inverted, normal, and diminished

4-62. With the object located between the focal point and the concave mirror surface, the image will be what type?

1. Virtual, erect, reverted, and enlarged
2. Real, inverted, normal, and diminished
3. Virtual, erect, normal, and diminished
4. Real, inverted, reverted, and enlarged

4-63. What type of mirror is used as reflectors on most external automobile lights?

1. Convex spherical
2. Concave spherical
3. Convex cylindrical
4. Concave cylindrical

4-64. All rays which strike a parabolic mirror reflect from the mirror nearly parallel with each other and form a beam of light which diverges

1. slightly
2. moderately
3. considerably
4. profusely

Learning Objective: Solve problems related to lens formulas. Textbook page 4-19.

4-65. Which of the following is NOT a factor in the focal length formula?

1. F
2. D_o
3. D_i
4. i

4-66. If you have a lens with a focal length of 2 inches and the object is at infinity, what is the distance of the image?

1. Infinity
2. 2 in.
3. 1/2 in.
4. 4 in.

4-67. Use the lens formula to determine D_i when $F = 3$ inches and $D_o = 5$ inches.

1. 2.5 in.
2. 5.0 in.
3. 7.5 in.
4. 10.0 in.

4-68. Given D_o of 2 inches and a focal length of -3 inches, find D_i.

1. -6 in.
2. +6 in.
3. +1.2 in.
4. -1.2 in.

Assignment 5

Lenses (continued); Basic Optical Systems

Textbook Assignment: Pages 4-19 through 5-6

Learning Objective: Solve problems by working with the magnification formula. Textbook pages 4-19 through 4-22.

5-1. When used as a magnifying lens, a positive lens

1. makes the light rays subtend a larger angle at an observer's eye than is possible with the unaided eye
2. makes the light rays subtend a smaller angle at an observer's eye than is possible with the unaided eye
3. uses the principle of optical illusion
4. tends to bring objects closer to the unaided eye

5-2. If the image distance is 4 inches and the object distance is 2 inches, what is the magnification?

1. 1
2. 2
3. 8
4. 4

5-3. You have an object 2 inches high, 3 inches from a lens of 2-inch focal length. What is the magnification?

1. 1
2. 2
3. 3
4. 4

5-4. What is the magnification if the image is the same size as the object?

1. 1
2. 0
3. -1
4. 1/2

5-5. A camera lens has a focal length of 5 inches. The object being photographed is a ship 100 yards long and 3,000 yards from the scope. What is the length of the image on the film?

1. 0.21599 in.
2. 0.00005 in.
3. 0.18 in.
4. 1.4 in.

5-6. What is considered to be the distance of distinct vision?

1. 6 in.
2. 8 in.
3. 9 in.
4. 10 in.

5-7. What is the magnifying power of a positive lens with a 10-inch fL?

1. 0.01
2. 0.1
3. 1.0
4. 10

5-8. What is the metric equivalent of 10 inches?

1. 25.4 dm
2. 0.0254 m
3. 2.54 cm
4. 0.254 m

Learning Objective: Identify the principles of the lens diopter and calculate dioptric strength and relative aperture. Textbook pages 4-22 through 4-24.

5-9. What kind of power is measured by a lens diopter?

1. Refractive
2. Diffractive
3. Attractive
4. Distractive

5-10. A lens with a focal length of 1 meter has a refractive power of

1. 1 diopter
2. 2 diopters
3. 3 diopters
4. 4 diopters

5-11. A convergent lens with a focal length of 40 centimeters has a power of

1. -2 diopters
2. -2.5 diopters
3. 2.0 diopters
4. 2.5 diopters

5-12. A divergent lens with a focal length of 20 centimeters has a power of

1. -2.5 diopters
2. -2.0 diopters
3. -5.0 diopters
4. 5.0 diopters

5-13. What is the dioptric strength of a lens with a focal length of 5 inches?

1. 16
2. 2
3. 8
4. 4

5-14. What is the name for the largest diameter in an optical system through which light can enter a lens to form an image?

1. Clarity
2. Intensity
3. Aperture
4. Focal length

5-15. A lens with a diameter of 50 mm and a focal length of 100 mm will have a relative aperture of

1. 0.5
2. 1.5
3. 2.0
4. 0.2

5-16. A lens having a diameter of 50 mm and a focal length of 100 mm will transmit how much light compared to a lens with a diameter of 100 mm and a focal length of 200 mm?

1. One-fourth as much
2. One-half as much
3. The same amount
4. Twice as much

5-17. A lens with a 50 mm diameter and a 100 mm focal length will transmit how much light compared to a lens of the same focal length and a 100 mm diameter?

1. One-fourth as much
2. One-half as much
3. The same amount
4. Twice as much

5-18. How much brighter an image will a camera with an f:1.9 lens form when compared to an f:3.6 lens?

1. 1.89X
2. 3.6X
3. 0.52X
4. 0.28X

Learning Objective: Identify the problems associated with lens aberrations and the methods used to correct them. Textbook pages 4-25 through 4-28.

5-19. Any defect in an image produced by an optical system or individual element is called a lens

1. asymmetry
2. aberration
3. error
4. fault

5-20. In chromatic aberration, which rays focus nearest to the lens?

1. Violet
2. Red
3. Orange
4. Indigo

5-21. Crown glass is more strongly convergent for blue rays than for

1. violet rays
2. red rays
3. indigo rays
4. green rays

5-22. The amount of spherical aberration in either a convergent or divergent lens is influenced by the thickness of the lens and its

1. refraction
2. transparency
3. homogeneity
4. focal length

5-23. How, if at all, does bending a lens affect focal length?

1. It reduces focal length
2. It increases focal length
3. It doubles focal length
4. It does not change the focal length

5-24. To reduce spherical aberration in a telescope, objectives are assembled with the crown side facing

1. forward
2. rearward
3. downward
4. upward

5-25. Spherical aberration in fire control instruments is usually eliminated by the use of a

1. bent lens
2. field stop
3. compound lens
4. thicker lens

5-26. What causes coma?

1. Refracted light rays through the center of a lens do not intersect rays refracted through other portions of the lens at a single point on the optical axis
2. Unequal refracting power of concentric ring surfaces of a lens for rays of light which come from a point to a distance off the optical axis
3. Rays from various surfaces come to a focus at the same point
4. Blurring of the image

5-27. A lens corrected for chromatic and spherical aberration, plus coma is called a/an

1. achromatic doublet
2. chromatic doublet
3. aplanatic lens
4. planatic lens

Learning Objective: Identify astigmatism, curvature of field, and distortion; and show how these aberrations are controlled. Textbook pages 4-28 through 4-31.

5-28. If equally sharp images of lines cannot be obtained when the lines run at angles to each other, the problem is called

1. astigmatism
2. achromatic aberration
3. chromatic aberration
4. spherical aberration

5-29. How is the image formed by a lens which shows astigmatism?

1. It converts a cone of light to an elongated oval in one plane, then compresses it to a circular bundle, and then it becomes oval again in the opposite plane
2. It converts a cone of light into an elongated oval in both planes
3. It converts a cone of light to a circular bundle in both planes
4. It converts a cone of light to a circular bundle in one plane, then compresses it to an oval, and then it becomes circular again in the opposite plane

5-30. What is the best way to reduce astigmatism in a lens?

1. Use a single bent lens
2. Use a compound bent lens
3. Use an achromatic lens
4. Use several lenses

5-31. If the point images of point objects can lie on a curved surface instead of a plane, the aberration is called

1. spherical
2. coma
3. astigmatism
4. curvature of field

5-32. Curvature of field is commonly corrected by using

1. field distorters
2. field flatteners
3. image distorters
4. image flatteners

5-33. Imperfect centration or irregularity of optical surfaces causes

1. coma
2. distortion
3. astigmatism
4. curvature of field

5-34. If magnification is less for objects off the axis, what kind of distortion do you have?

1. Barrel
2. Pin cushion
3. Correlated
4. Disjunctive

5-35. What kind of lens does a manufacturer use to let distortions cancel each other?

1. Single
2. Chromatic
3. Achromatic
4. Compound

5-36. If convergent and divergent lenses of slightly unequal curvature are pressed against each other, irregular colored bands or patches of color appear between the surfaces. What is this defect called?

1. Diopter rings
2. Newton's rings
3. Astigmatism
4. Curvature of field

Learning Objective: Trace the path of light through a thick lens and identify the factors peculiar to thick lenses. Textbook pages 4-33 through 4-35.

5-37. How many types of thick lenses will you be concerned with in the Navy?

1. One
2. Two
3. Three
4. Four

● In answering Items 5-38 through 5-41, refer to figure 4-41 in the text.

5-38. What type are the two lenses shown?

1. Equiconcave
2. Equiconvex
3. Chromatic
4. Achromatic

5-39. The lenses differ in their

1. index of refraction
2. radius of curvature
3. diameter
4. thickness

5-40. What type of ray passes through the optical center of the lenses and emerges from the lens parallel to the incident ray without deviation?

1. A
2. AA
3. B
4. BB

5-41. How does the refraction of the B rays compare in the two lenses?

1. Almost the same
2. Essentially different
3. The same
4. No resemblance

5-42. The front focal length (FFL) is defined as the distance measured from the principal focal point

1. on the left to the vertex of the front surface
2. on the right to the vertex of the front surface
3. in the middle to the vertex of the front surface
4. in the middle to the vertex of the rear surface

5-43. The distance measured from a principal plane to its corresponding principal focal point is called the

1. front focal equivalent
2. rear focal equivalent
3. front focal length
4. equivalent focal length

5-44. Two elements cemented together with their optical axis in alignment are called a

1. compound lens
2. reinforced single lens
3. doublet
4. double thicklet

5-45. The lenses of doublets too large in diameter to be cemented together form a lens combination called a/an

1. compound doublet
2. air-spaced doublet
3. twin coublet
4. complex doublet

5-46. In a dialyte compound lens, the inner surfaces of the two elements do NOT have the same

1. refraction
2. diffraction
3. curvature
4. dielectric

Learning Objective: Recognize the uses of reticles, color filters, and dichroic crystals. Textbook pages 4-37 and 4-38.

5-47. What is the function of a reticle?

1. To serve as a vernier gage
2. To superimpose reference marks on a target image
3. To engrave reference marks on a plano surface
4. To reflect the line of sight into the eye of the observer

5-48. What color filters are generally used in fog or haze to filter out scattered blue and green light?

1. Green, amber, and smoke
2. Green, yellow, and amber
3. Blue, yellow, and amber
4. Red, yellow, and amber

5-49. What color filters are useful in bright sunlight to reduce glare?

1. Green, yellow, and amber
2. Yellow, amber, and smoke
3. Amber, smoke, and green
4. Smoke, green, and red

5-50. A dichroic crystal allows transmission of light vibrating in how many directions?

1. One
2. Two
3. Three
4. Four

Learning Objective: Identify parts and functions of the human eye. Textbook pages 5-1 through 5-5.

5-51. A combination of optical components arranged to perform one or more optical functions is the definition of an optical

1. system
2. element
3. order
4. input

5-52. On which part of the human eye is the image produced?

1. Cornea
2. Retina
3. Pupil
4. Sclera

5-53. The human eye is held in shape by the

1. retina and the ciliary muscle
2. ciliary muscle and sclera
3. sclera and pressure of its viscous content
4. iris and muscles

5-54. In the human eye, what focuses the eyelens?

1. Pupil
2. Retina
3. Posterior chamber
4. Ciliary process

5-55. The anterior chamber of the human eye is a space between the

1. cornea and iris
2. cornea and sclera
3. iris and sclera
4. iris and lens

5-56. The function of the suspensory ligaments is to attach the lens to the

1. cornea
2. ciliary muscle
3. vitreous humor
4. sclera

5-57. What part of the human eye acts like the diaphragm of a camera?

1. Retina
2. Sclera
3. Iris
4. Pupil

5-58. What is the first refracting surface for light entering the eye?

1. Cornea
2. Iris
3. Pupil
4. Lens

5-59. A transparent elastic body with a dense inside core and a less dense outer layer is the definition of the

1. cornea
2. retina
3. pupil
4. lens

5-60. What is the name of the process when your eye changes focus from a near point to a far point?

1. Acclimation
2. Refraction
3. Accommodation
4. Illumination

5-61. A normal eye has the ability to focus on an object at a near point of about

1. 5.0 in.
2. 5.9 in.
3. 7.0 in.
4. 8.9 in.

5-62. The eye is the same as a camera only in respect to which of these components?

1. Lens
2. Iris
3. Sclera
4. All of the above

5-63. How is the process described after an image is formed on the retina of the eye?

1. Mechanical
2. Physical
3. Sensitized
4. Psychological

5-64. With what part of a camera may the iris of the eye be compared?

1. Retina
2. Lens
3. Aperture
4. Diaphragm

5-65. Which of these statements describes in part the process of vision?

1. You see the retinal image
2. Light energy striking the retina of the eye is the terminal point in vision
3. The retinal image forms a pattern that provides information to the nervous system
4. We are aware of our eye movements

5-66. If you fix your eyes on a point of some unfamiliar picture or printed page, most of what you are viewing will be

1. invisible
2. barely visible
3. in sharp focus
4. magnified

5-67. Light-sensitive elements of the eye are of two kinds, namely,

1. rods and cones
2. nerve tissue and fibers
3. nerve fibers and blood vessels
4. tissues and vessels

5-68. What is the most sensitive area of the retina?

1. Blind spot
2. Fovea
3. Optic nerve
4. Choroid

Learning Objective: Recognize the elements of good vision as well as defects in normal and night vision. Textbook pages 5-5 and 5-6.

5-69. What is rhodopsin?

1. A violet photosensitive pigment in the retinal cones
2. A red photosensitive pigment in the retinal rods
3. A violet photosensitive pigment in the retinal rods
4. A red photosensitive pigment in the retinal cones

5-70. What part of the eye has the most to do with night vision?

1. Pupil
2. Sclera
3. Cones
4. Rods

5-71. Which of these are primary colors?

1. Red, white, and blue
2. Green, yellow, and blue
3. Red, green, and blue
4. Blue, red, and yellow

5-72. What is the most common color deficiency in humans?

1. Red-green
2. Green-blue
3. Blue-yellow
4. Yellow-green

5-73. What is visual acuity?

1. Percentage of rods in the retina
2. Percentage of cones in the retina
3. Sharpness of vision
4. Ability to see at night

5-74. The standard for measuring visual acuity is the

1. 5-minute square letter
2. 10-minute square letter
3. 20-minute square letter
4. 40-minute square letter

5-75. A vision of 20/20 means that at a distance of 20 feet, the person can read a line of letters on a chart which is

1. 20 mm high
2. normally read at 10 feet
3. 20 mils high
4. normally read at 20 feet

Assignment 6

Basic Optical Systems (Continued)

Textbook Assignment: Pages 5-6 through 5-31

Learning Objective: Indicate functions of the normal eye. Textbook pages 5-6 and 5-7.

6-1. What is meant by the resolving power of the eye?

1. The ability to distinguish colors
2. The ability to distinguish distances
3. The ability of the eye to revolve
4. The ability to distinguish between adjacent points

6-2. The normal eye can distinguish between equally bright objects separated by an angle of only

1. 1 minute
2. 2 minutes
3. 3 minutes
4. 4 minutes

6-3. Resolution of an image depends upon all EXCEPT which of the following factors?

1. Retinal location of the image
2. Density of the image
3. Brightness of the image
4. Adequate time for stimulation

6-4. About how much brighter does an object seem when viewed with two eyes as when viewed with just one?

1. 50%
2. 20%
3. 30%
4. 40%

Learning Objective: Indicate characteristics of normal vision as well as abnormal vision. Textbook pages 5-7 though 5-12.

6-5. The field of view with both eyes is normally about

1. 160° on the horizontal and 70° on the vertical
2. 70° on the horizontal and 160° on the vertical
3. 80° on the horizontal and 150° on the vertical
4. 150° on the horizontal and 80° on the vertical

6-6. What is the basic characteristic of stereoscopic vision?

1. The difference in focal points of the two eyes
2. Both eyes forming an identical image
3. The overlapping area seen by both eyes
4. The difference in the images formed on the two retinas

6-7. The distance between the pupils is called

1. interlinear distance
2. interpupillary distance
3. interdimensional distance
4. interstereoscopic distance

6-8. If your interpupillary distance is 60 mm, and other factors of depth perception are equal, your stereoscopic vision would improve if the distance between your pupil exceeded

1. 34 mm
2. 44 mm
3. 54 mm
4. 64 mm

6-9. How do binoculars affect your stereoscopic vision?

1. They reduce the interpupillary distance
2. They increase the interpupillary distance
3. They reduce the distance of the object from the eye
4. They increase the angles of convergence

410

6-10. Under excellent conditions of observation, a well-trained observer can discern an average minimum difference of about

1. 50 seconds or arc
2. 40 seconds of arc
3. 24 seconds of arc
4. 12 seconds of arc

6-11. Because of chromatic aberration, which colors are automatically focused on your retina?

1. Green and yellow
2. Yellow and blue
3. Blue and red
4. Red and green

6-12. What is the name of the defect whereby the surface of the eye is more strongly curved in one plane than in another?

1. Hyperopia
2. Myopia
3. Astigmatism
4. Cataract

6-13. If the refracting mechanism of the eye is too strong, the eye suffers from

1. hyperopia
2. myopia
3. astigmatism
4. dyspepsia

6-14. What vision defect is characterized if the refracting mechanism is too weak?

1. Hyperopia
2. Myopia
3. Astigmatism
4. Dyspepsia

6-15. What is a good way to rest your eyes?

1. Rub your eyes for a while
2. Obtain stronger eye glasses
3. Look at small objects for a while
4. Look at distant objects for a while

6-16. What is the distance of the most distinct vision of the eye?

1. 6 in.
2. 8 in.
3. 10 in.
4. 12 in.

6-17. Which of these choices is NOT a basic function of an eyepiece?

1. Forming an aberration-free image
2. Magnifying
3. Allow the observer's eye to be placed at the exit pupil
4. Removing parallax

6-18. What is the nearest the normal eye can approach an eyepiece surface with comfort?

1. 8 to 10 mm
2. 10 to 12 mm
3. 12 to 14 mm
4. 14 to 16 mm

6-19. Optical instruments may be classified as

1. monocular or binocular
2. objective or subjective
3. divergent or convergent
4. magnifying or aberration-free

6-20. What is meant by a dominant eye?

1. One that magnifies more than the other
2. One that is used more than the other
3. One that is aberration-free
4. One that is more accommodating

6-21. When focusing an instrument with an adjustable eyepiece, your first step is to

1. move the eyepiece slowly in until the target image is sharply defined
2. move the eyepiece to the extreme plus diopter position
3. allow your eye to relax completely
4. move the eyepiece slowly out until the target image is sharply defined

---

Learning Objective: Identify the types and makeup of eyepieces used in the Navy. Textbook pages 5-13 through 5-17.

6-22. Telescopes provide a sufficiently wide range of accommodation if the magnification is

1. 10X or less
2. 8X or less
3. 6X or less
4. 4X or less

441

6-23. Eyepieces in military optical instruments consist of

1. one, two, or three lenses
2. two, three or four lenses
3. three, four, or five lenses
4. four, five, or six lenses

6-24. If the third element is used, what is it called?

1. The tertiary element
2. The intermediate lens
3. The backup lens
4. The field lens

6-25. What is the makeup of the Huygens eyepiece?

1. One convexo-plano and one concavo-plano lens
2. Two concavo-plano lenses
3. Two convexo-plano lenses
4. Two convexo-plano and one concavo-plano lens

6-26. One feature of the Huygens eyepiece is that it

1. has no chromatic aberration
2. has no spherical aberration
3. can be made free of coma
4. can have positive astigmatism

6-27. The Ramsden eyepiece is made of

1. one plano-convex lens
2. two plano-concave lenses
3. two plano-convex lenses
4. one plano- and one plano-convex lens

6-28. The outstanding disadvantage of the Ramsden eyepiece is its

1. serious spherical aberration
2. extensive coma
3. serious chromatic aberration
4. relatively low magnifying power

6-29. What advantage does the Kellner eyepiece enjoy over the Ramsden?

1. Less spherical aberration
2. The eyelet is a doublet
3. Less chromatic aberration
4. Reduced coma

6-30. What characteristic(s) of component lenses make(s) an eyepiece symmetrical?

1. Identical diameters
2. Identical diameters, focal lengths, thicknesses, and indexes of refraction
3. Identical diameters and focal lengths
4. Identical diameters, focal lengths, and indexes of refraction

6-31. What type of eyepieces are used extensively in rifle scopes?

1. Kellner and Ramsden
2. Huygens and Kellner
3. Huygens and symmetrical
4. Symmetrical and Kellner

6-32. A planoconvex triplet field lens and a single planoconvex eyelens are part of the

1. Ramsden eyepiece
2. Huygens eyepiece
3. Kellner eyepiece
4. Orthoscopic eyepiece

6-33. The orthoscopic eyepiece is so called because it is free of

1. distortion
2. chromatic aberration
3. spherical aberration
4. coma

6-34. Which lens converges light which otherwise would miss the intermediate lens?

1. Triplet
2. Singlet
3. Field lens
4. Eyelens

Learning Objective: Recognize the makeup and construction of the simple telescope. Textbook pages 5-17 through 5-19.

6-35. In its simplest form, a telescope consists of a/an

1. lens and a mirror
2. mirror and an objective
3. objective and a diaphragm
4. objective and an eyepiece

6-36. In the process of refraction and reflection by a telescope system, the image becomes

1. refracted
2. reflected
3. reverted
4. inverted

6-37. What kind of telescopes give the viewer an inverted view?

1. Astronomical
2. Field
3. Inversion
4. Objective

6-38. Why is it NOT practical to design a telescope lens bigger than 40 inches?

1. Cost of good glass
2. Weight and physical character of glass
3. Material is not available
4. Mounting would be too massive

6-39. At least how many elements must an objective lens have to correct aberrations?

1. One
2. Two
3. Three
4. Four

6-40. How much chromatic aberration does a mirror have?

1. A little
2. None
3. Moderate
4. Extensive

6-41. Why did the Corning Glass Company use Pyrex rather than ordinary glass in making the objective for the Mt. Palomar telescope?

1. Pyrex expands and contracts less than ordinary glass
2. Pyrex expands less but contracts more than ordinary glass
3. Pyrex expands more but contracts less than ordinary glass
4. Pyrex expands and contracts more than ordinary glass

6-42. What kind of image is formed in the focal plane of the objective lens in figure 5-25 of the text?

1. Real, inverted, reverted, and diminished
2. Real, inverted, reverted, and enlarged
3. Virtual, inverted, reverted, and diminished
4. Virtual, inverted, reverted, and diminished

6-43. The diameter of the bundle of light leaving an optical system is the definition of the

1. free aperture
2. exit pupil
3. eye distance
4. true field

6-44. The numerical measure of the distance from the rear surface of the rear eyelens to the fixed position of the exit pupil defines what optical term?

1. Free aperture
2. Exit pupil
3. Eye distance
4. True field

6-45. The maximum cone or fan of rays, subtended at the entrance pupil, that is transmitted by the instrument to form a usable image is the definition of the

1. free aperture
2. exit pupil
3. apparent field
4. true field

Learning Objective: Identify the features of the Galilean telescope and compute magnification when given formulas to use. Textbook pages 5-20 through 5-25.

6-46. Which of the following features was NOT present in Galileo's first telescope?

1. Negative eyelens
2. Converging rays
3. Objective
4. Real image

6-47. What was the power of Galileo's first telescope?

1. 30
2. 20
3. 10
4. 5

6-48. The terrestrial telescope is used to view objects as normal and

1. diminished
2. reverted
3. inverted
4. erect

6-49. What diopter setting is used if all light rays from any point source located at infinity emerge from the eyepiece parallel?

1. Zero
2. -1
3. ±1
4. -1/2

6-50. In a Galilean telescope, what controls the field of view?

1. Diameter of the objective
2. Field stop
3. Free aperture
4. Exit pupil

6-51. Any astronomical telescope can be converted to a terrestrial telescope by inserting a lens between the eyepiece and the objective to

1. increase the visual angle and magnify
2. erect the image and magnify
3. refract and magnify
4. diverge and magnify

6-52. In the magnification formula, if D_o is 3 focal lengths D_i is 2 focal lengths, then M equals

1. 0.5
2. 0.66
3. 1.5
4. 0.33

6-53. If the objective focal length is 4 inches, and the eyelens focal length is 2 inches, then M equals

1. 0.5
2. 1.0
3. 1.5
4. 2.0

6-54. If the basic telescope magnification is 6 and the magnification of the erector is 0.5, then the magnification of the telescope is

1. 1 power
2. 2 power
3. 3 power
4. 4 power

6-55. What is the magnification in figure 5-30C of the text?

1. 2X
2. 4X
3. 8X
4. 16X

6-56. If two erecting lenses have the same diameter, thickness, and index of refraction, but have different focal lengths, then these lenses are referred to as

1. symmetrical
2. identical
3. asymmetrical
4. dissimilar

6-57. In figure 5-32 of the text, what happens to the rays as they enter the 1st erector?

1. They are refracted
2. They are diffracted
3. They are diffused
4. They are subtended

6-58. In figure 5-32 of the text, rays which enter the 2nd erector are always

1. suffused
2. parallel
3. fixed
4. diffused

6-59. What, if anything, happens to the field of view as magnification increases?

1. It increases
2. It decreases
3. It blurs
4. Nothing; it remains unchanged

6-60. Why are hand held telescopes usually limited to 6X?

1. To reduce eye strain
2. To increase fine detail
3. To reduce weight
4. To control apparent target movement

6-61. How many stages of magnification are there between two limits of a variable power telescope?

1. 6
2. 8
3. 10
4. Unlimited

6-62. In the change of power telescope, for how many positions of the erecting lens are the two image planes conjugate?

1. One
2. Two
3. Three
4. Four

6-63. In a variable power system, high power provides how much more magnification than low power?

1. One to two times
2. Two to three times
3. Three to four times
4. Four to five times

6-64. If two porro prisms are placed within the focal length of the objective lens, what kind of image does the viewer see?

1. Inverted and reverted
2. Erect and normal
3. Erect and reverted
4. Inverted and normal

Learning Objective: Indicate the construction and uses of the gunsight telescope and the microscope. Textbook pages 5-26 through 5-30.

6-65. A gunsight telescope improves the view of distant targets but can NOT do which of the following?

1. Concentrate a greater quantity of light from the target than the unaided eye can gather
2. Erect the target image
3. Superimpose a reticle upon the target
4. Indicate the relative distance of the target

6-66. In a gunsight that has a lens-erecting system, in how many places can the reticle be placed?

1. One
2. Two
3. Three
4. Four

6-67. Parallax occurs because what two elements do NOT line up?

1. Field of view and reticle
2. Reticle and erector focal plane
3. Objective image plane and erector focal plane
4. Field of view and erector focal plane

6-68. Which of these methods can be used to find the power of a telescope?

1. $M = \frac{f_o}{f_e}$
2. $M = \frac{f_e}{f_o}$
3. $M = \frac{EP}{FA}$
4. $M = \frac{\text{true field}}{\text{apparent field}}$

6-69. For measuring the diameter of an exit pupil, what is the best technique?

1. Use a dynameter
2. Focus on a piece of paper
3. Measure the eyepiece
4. Divide the focal length of the instrument by the diameter of the objective

6-70. The dynameter reticle is graduated in

1. 0.5 mm
2. 0.750 mm
3. 1.0 mm
4. 1.25 mm

6-71. What term is defined as the angular area of a target which can be transmitted through the objective of an instrument to form an image?

1. Apparent field
2. Induced field
3. True field
4. Hypothetical field

6-72. What are the two types of microscopes?

1. Unaided and electronic
2. Biological and microbiological
3. Aided and unaided
4. Simple and compound

6-73. Microscopes increase the usefulness of the eye, because the eye is

1. a short-range optical instrument of high acuity
2. a long-range optical instrument of low acuity
3. a long-range optical instrument of high acuity
4. a short-range optical instrument of low acuity

6-74. Given D_o as 0.5 and D_i as 8 inches, M equals

1. 16
2. 12
3. 8
4. 4

Assignment 7

Design and Construction; Maintenance Procedures - Part I

Textbook Assignment: Pages 6-1 through 7-3

Learning Objective: Recognize the mechanical features of optical instruments used in the Navy. Textbook pages 6-1 through 6-6.

7-1. Which of the following factors influences the design of an optical instrument?

1. Nameplate data
2. Use or application of the instrument
3. Location of the instrument when not in use
4. Who is going to repair the instrument

7-2. Binocular bodies are usually made of

1. cast bronze
2. cast iron
3. cast aluminum
4. steel alloys

7-3. The housing of most gunsight telescopes is made of which of the following materials?

1. Cast bronze
2. Cast iron
3. Cast aluminum
4. Magnesium alloy

7-4. Wha[illegible] the main factor considered in the design [illegible]rangement of a housing?

1. Accessibility of optical and mechanical components
2. Location of optical and mechanical components
3. Material from which the body is made
4. Type of prism mount to be used

7-5. What is/are the function(s) of the machined mounting pads used on gunsight housings?

1. To provide accurate alignment
2. To provide vertical mounting surfaces
3. To provide horizontal mounting surfaces
4. To provide all of the above

7-6. An instrument housing is designed with access holes and cover plates for which of the following purposes?

1. For ease in assembling and adjusting enclosed parts
2. For reading the instrument
3. For an escape route of trapped gases
4. For all of the above purposes

7-7. What is the function of a lens cap?

1. To reduce glare caused by sunlight
2. To protect the observer's eyes
3. To protect the eyelens or objective lens
4. To limit the passage of light

7-8. What is/are the function(s) of the eye guards?

1. To protect the observer's eye
2. To keep out stray light rays
3. To maintain proper eye distance
4. To do all of the above

7-9. Where is a field stop normally placed in an optical instrument?

1. At the image plane
2. At the entrance pupil
3. At the exit pupil
4. Between the erectors

7-10. A component located to limit the size of the entrance pupil is called a/an

1. aperture stop
2. antiglare stop
3. field stop
4. lens stop

Learning Objective: Recognize the problems of designing the proper mounts for optical instruments. Textbook pages 6-7 through 6-10.

7-11. Antiglare stops are located within the

1. front focal length of the objective lens
2. back focal length of the objective lens
3. front focal length of the erector lens
4. back focal length of the erector lens

7-12. Why do lens spacers have machine beveled ends where they contact the lenses?

1. To separate the lenses
2. To fit in the lens cell
3. To fit the retaining ring
4. To provide a snug fit with no sharp edges

7-13. How are most retainer rings held in place?

1. By a tight fit
2. By a setscrew
3. By a lock washer
4. By another retainer ring

7-14. Axial adjustment of a single lens in an instrument is normally accomplished by means of a/an

1. burnished mount
2. eccentric mount
3. externally adjusted lens
4. externally threaded mount

7-15. How, if at all, can you obtain additional movement of the optical axis other than that provided by the eccentric ring and mount?

1. Replace the eccentric rings
2. Reverse the lens
3. Rotate the lens in its mount
4. You cannot obtain additional movement

Learning Objective: Indicate the types of mounting prisms used in Navy optical instruments. Textbook pages 6-10 through 6-12.

In items 7-16 through 7-18, select from column B the type of mount that fits the description in column A.

	A. Description	B. Type of Mount
7-16.	Concentric bearing surface machined offset from the mechanical axis	1. Porro prism mount 2. Roofedge prism mount
7-17.	Right angle bracket on which the prism rests	3. Right angle prism mount 4. Eccentric mount
7-18.	Flat metal plane shaped to fit the interior of a housing	

7-19. Lean exists in prism clusters when the prisms are at right angles to each other.

7-20. What device is used in a porro prism cluster to prevent stray light rays from entering the prism surfaces?

1. A metal shield over the prism
2. A metal shield over the prism strap
3. A prism collar
4. A spring clip

7-21. Adjustments of the distance between a reticle and eyepiece in an optical instrument may be accomplished by which of the following devices?

1. Rack and pinion
2. Draw tube
3. Rotatable eyepiece
4. All of the above

Learning Objective: Identify the focusing arrangements with which an Opticalman will work and the makeup of eyepiece mounts. Textbook pages 6-12 through 6-17.

7-22. Which of these focusing arrangements consists of a metal tube which contains the lenses and their retainer ring and can be secured to the guide tube or withdrawn from it?

1. Draw tube
2. Spiral keyway eyepiece
3. Fixed eyepiece
4. Multiple lead thread

7-23. Which focusing arrangement is a modification of the draw tube?

1. Spiral keyway eyepiece
2. Fixed eyepiece
3. Internal-focusing eyepiece
4. Multiple lead thread eyepiece

7-24. In which focusing arrangement does the eccentric plate slide the lens mounts from maximum to minimum throw with a half-turn or less of the focusing knob?

1. Spiral keyway eyepiece
2. Fixed eyepiece
3. Internal-focusing eyepiece
4. Draw tube

7-25. Which type of eyepiece is generally preferred in instruments with reticles?

1. Internal-focusing
2. Fixed
3. Multiple lead thread
4. Draw tube

7-26. Which eyepieces can be sealed to prevent entrance of foreign matter and moisture?

1. Spiral keyway
2. Multiple lead thread
3. Draw tube
4. Internal-focusing

7-27. Which of the following items best describes the light rays leaving an instrument which has a fixed-type eyepiece?

1. Slightly convergent
2. Parallel
3. Slightly divergent
4. All of the above

Learning Objective: Indicate the types and functions of bearings used in Navy optical gear. Textbook pages 6-17 through 6-19.

7-28. In an optical instrument, what is the function of a bearing?

1. To reduce friction
2. To guide and support reciprocating elements
3. To act as a locking device
4. To act as a braking device

7-29. What type of bearing load directs the load along the surface of an object?

1. Normal
2. Radial
3. Axial
4. Angular

7-30. Sliding surface bearings are used in which of the following equipment?

1. On a lathe
2. In a car engine
3. On gunsights
4. All of the above

7-31. What is the purpose of the square surface bearing used in optical instruments?

1. To support adjusting screws
2. To act as a locating bearing
3. To hold parts inside the instrument
4. To do all the above

In items 7-32 through 7-34, select from column B the type of ball bearing used for carrying the shaft load in column A.

A. Shaft Load

7-32. Loads applied to a plane perpendicular to the axis of rotation

7-33. Loads applied in the same direction as the axis of the shaft

7-34. Loads having both radial and axial thrust

B. Type of Ball Bearing

1. Angular
2. Trunnion
3. Radial
4. Thrust

7-35. Preloading is the arrangement of pairs of angular ball bearings so that the angular contact surfaces of the outer and inner races of one bearing exert a force which opposes the outer and inner races of the other bearing.

7-36. To compensate for wear in ball bearings, what must you do?

1. Replace them
2. Adjust them
3. Use more lubricant
4. Use heavier lubricant

Learning Objective: Identify the types and functions of gears used in Navy optical equipment. Textbook pages 6-20 and 6-21.

7-37. What is the most common type of gear used in optical instruments to transmit power?

1. Bevel gear
2. Spur gear
3. Miter gear
4. Rack and pinion

7-38. Small spur gears are usually made of all EXCEPT which of the following metals?

1. Brass
2. Aluminum
3. Steel
4. Cast iron

7-39. A miter gear is used to

1. increase the speed of a bevel gear
2. decrease the speed of a bevel gear
3. change the direction of motion 90° with a decrease in speed
4. change the direction of motion 90° with no change in speed

7-40. When a double-lead worm is turned two revolutions, how many teeth will the sector advance?

1. Six
2. Two
3. Three
4. Four

7-41. Which of the following gears is mated at 45° angles?

1. Bevel
2. Spur
3. Worm
4. Helical

Learning Objective: Recognize the types and uses of sealing compounds, gaskets, O-rings, and other sealing devices used in optical instruments. Textbook pages 6-22 through 6-26.

7-42. Why are optical instrument bodies sealed?

1. To withstand immersion in water
2. To maintain cleanliness of the optics
3. To maintain internal nitrogen pressure
4. To do all the above

7-43. Which of the following characteristics best describes modern sealing compounds?

1. Hard to work with
2. Require short cure time
3. Require long cure time
4. Nonflexible

7-44. If the proper amount of sealant is used, lenses can be left cocked in their mounts.

7-45. The primary reason for sealing optical instruments is to

1. close all openings
2. hide all joints
3. hide all setscrews
4. make your instrument look neat

7-46. For economy reasons, you should replace only those flat gaskets that are defective.

7-47. An O-ring prevents internal and external leakage by distorting under pressure, thereby flowing into, filling, and sealing a passage to prevent fluid flow.

7-48. O-rings may wear out due to age and temperature changes.

7-49. O-rings may be installed with wooden dowels.

7-50. Prior to installing a new O-ring, you should check the package to determine the

1. expiration date of the old O-ring
2. cure date
3. manufacturer of the O-ring
4. proper lubricant to use on the O-ring

2Q 80 Expiration Date: May 82

Figure 7A

7-51. In the above figure, the 2 stands for

1. February
2. two in the package
3. the second quarter
4. the expiration month

Learning Objective: Indicate the type and use of lubricants in optical instrument repair. Textbook pages 6-26 and 6-27.

7-52. The main consideration in selecting the proper lubricant is the temperature zone in which the instrument is to be used.

7-53. What is the primary purpose for using grease or oil in an optical instrument?

1. To prevent wear
2. To snug the fit
3. To provide a smooth action
4. To seal the instrument

7-54. Which of the following features is/are required of grease containers?

1. They should be fitted with a cap
2. They should be covered when not in use
3. They should be labeled properly
4. All of the above

Learning Objective: Indicate the procedures for inspecting optical instruments. Textbook pages 7-1 and 7-2.

7-55. If an optical instrument is in a shipping container which will not close completely, what should you do?

1. Slam the lid closed
2. Throw the container away
3. Examine the instrument and container to identify the cause
4. Use the installed catches to close the container

7-56. The purpose of optical instrument inspection is to

1. increase the skills of repairmen
2. determine the cause of defects
3. maintain a constant shop workload
4. reduce excess work caused by unnecessary repairs

7-57. When should you record all findings on a casualty analysis inspection sheet?

1. During predisassembly inspection
2. During post disassembly inspection
3. Before predisassembly inspection
4. After post disassembly inspection

7-58. Backlash in the focusing eyepiece is usually caused by a

1. tight stop or retainer ring
2. loose stop or retainer ring
3. distorted stop or retainer ring
4. defective stop or retainer ring

7-59. During inspection of an instrument, you find that the focus adjustment binds. This trouble is probably caused by

1. a tight seal
2. improper lubrication
3. improper gear mesh
4. excessive internal pressure

7-60. When the eyepiece is at midthrow, the index marks will point to

1. 15 diopters
2. 10 diopters
3. 5 diopters
4. 0 diopters

7-61. If the color filters of an instrument do not move in and out of the line of sight and the filter shaft cannot be turned, what is the probable cause?

1. The gears are slipping
2. A gear has become detached from the shaft
3. The shaft is bent or corroded
4. The shaft is broken

7-62. Loose or broken internal parts in a small optical instrument can most easily be detected by

1. sending the instrument to the factory
2. X-raying the instrument
3. shaking the instrument and listening for rattling sounds
4. disassembling the instrument

7-63. When there is no pressure in a gas-sealed instrument, the problem could be caused by

1. a defective pressure gage
2. defective gaskets
3. badly corroded bearing surfaces
4. loose prisms

Learning Objective: Distinguish elements within an optical system and point out defects within the elements. Textbook page 7-3.

7-64. Contamination or dark spots on optics are caused by

1. scratches
2. moisture
3. oil
4. dust

7-65. Brown or green patches on lenses indicate the presence of

1. fungus or watermarks
2. chips or scratches
3. grease or oil
4. dirt or dust

7-66. Irregularly shaped splotches between elements of a lens indicate

1. separated balsam
2. fungus
3. moisture
4. chips

7-67. If you view an optical element under a strong white light, properly coated optics will show a

1. deep blue reflection
2. green reflection
3. reddish purple reflection
4. yellow reflection

452

Assignment 8

Maintenance Procedures - Part I (Continued)

Textbook Assignment: 7-3 through 7-24

Learning Objective: Recognize defects within the elements of an optical system. Textbook pages 7-3 and 7-4.

8-1. Why are reticles NEVER coated?

1. Coating would distort the reticle pattern
2. The color of the coating would be objectionable
3. The coating would be in an image plane and flaws would be visible
4. For all the above reasons

8-2. Wear or peeling of the silvered surface of mirrors shows up as a

1. reddish color
2. bluish color
3. greenish color
4. yellowish color

8-3. Which of these lens defects is the least objectionable?

1. Ring
2. Chip
3. Notch
4. Crack

8-4. What optical defect appears as a break at the edge of a lens caused by uneven pressure on the seat of the lens mount?

1. Scratch
2. Stripe
3. Chip
4. Notch

8-5. The optical defect which appears as a ground off surface of a lens is a

1. chip
2. notch
3. scratch
4. stripe

8-6. If an optical defect appears visible as you rotate a lens completely, that defect is known as a

1. chip
2. scratch
3. notch
4. stripe

8-7. A fracture of a lens caused by a sudden change of temperature is known as a

1. chip
2. crack
3. notch
4. scratch

8-8. Veins or cords running through the glass are called

1. striae
2. chips
3. scratches
4. cracks

8-9. Which of these defects is NOT caused by a problem with the glass?

1. Scratch
2. Crack
3. Blister
4. Striae

453

8-10. Blisters in lenses may be caused by which of the following?

1. Poor workmanship in cementing lenses
2. Chips
3. Cracks
4. Defective glass used in lens manufacture

8-11. Bacterial growth can cause a lens defect known as

1. blisters
2. stains
3. rings
4. bubbles

Learning Objective: Recognize the stages of testing an optical system for parallax, collimation, image fidelity, and astigmatism. Textbook pages 7-4 through 7-7.

8-12. A rapid collimation check can be obtained with the aid of a/an

1. collimator
2. dynamotor
3. auxiliary telescope
4. outside target

8-13. Lean may be present in optical instruments if they have

1. crosslines
2. lens-erecting systems
3. prism-erecting systems
4. parallax

8-14. The clarity and accuracy of an image produced by an optical instrument is called image

1. fidelity
2. testing
3. reproduction
4. resolution

8-15. The resolution requirements in terms of angle in the field for the telescopic alidade are

1. 56
2. 40
3. 36
4 20

8-16. What size is the objective in a pair of 7 X 50 binoculars?

1. 1 1/4 in.
2. 35 mm
3. 1 1/2 in.
4. 50 mm

8-17. The resolving power of the eye is equal to

1. 1 minute of arc
2. 2 minutes of arc
3. 3 minutes of arc
4. 4 minutes of arc

8-18. Why is it better to use a high magnification instrument if you are going to use the instrument for a long time?

1. High-power instruments are free of aberrations
2. Effects of eye fatigue will be reduced
3. High-power instruments produce a brighter image
4. A wider focusing range is available

Learning Objective: Indicate the procedure for testing an optical system for astigmatism and other optical defects. Textbook pages 7-7 through 7-9.

8-19. What is the maximum allowable difference between the horizontal and vertical lines for the instrument being tested?

1. 0.60 diopters
2. 0.45 diopters
3. 0.30 diopters
4. 0.15 diopters

8-20. The reason for using an auxiliary telescope during an astigmatism test is that the auxiliary

1. doubles the accuracy of the test
2. multiplies the accuracy of the test by a factor equal to its magnification
3. compensates for any astigmatism in the eyes of the repairman
4. increases the accuracy by a factor equal to the square of its power

454

8-21. What is the maximum allowable diopter difference for a 5-power auxiliary telescope?

1. 1.35
2. 2.40
3. 3.75
4. 5.40

8-22. How do you check an optical instrument for flares or ghosts?

1. Point it toward a small, bright object against a dark background and focus sharply
2. Adjust the auxiliary telescope diopter ring
3. Check the optical surfaces for close tolerances
4. Sight the test pattern with the instrument to be tested

8-23. If an object appears brighter when viewed with the naked eye than when viewed with a telescope, this difference could be caused by

1. changing light conditions
2. an oil film on the optics
3. sharply contrasting areas of the target
4. excessive light transmission

Learning Objective: Identify the skills and tools needed to overhaul and repair optical instruments. Textbook pages 7-9 through 7-14.

8-24. A fingerprint is especially troublesome on an optic because it

1. reduces light transmission
2. is hard to remove
3. will etch the glass
4. distorts images

8-25. The most critical tools used in optical repair work are those classified as

1. expensive
2. precision
3. handtools
4. special tools

8-26. The first step in making a tool is to

1. make a sketch to show exact dimensions and the material to be used
2. secure a template of the tool to be made
3. transcribe dimensions from a similar tool
4. check the machine out thoroughly on which the tool will be made

8-27. To remove or install various types and sizes of retainer rings, a pin wrench is designed to

1. be adjustable
2. have interchangeable tips
3. grip the outer surface of the ring
4. function without slipping

8-28. Which of these casualties could result from improper use of a pin wrench?

1. Damaged optics
2. Burred threads
3. Stripped retainer ring slots
4. All of the above

8-29. Proper use of a grip wrench requires you to

1. select a size that will be a force fit
2. squeeze the wrench as much as possible to remove a part
3. place the wrench on a reinforced tube section when possible
4. force it onto the part to be turned

8-30. Which of these tools can be used only for a specific task?

1. Bench block
2. Hinge pin puller
3. Grip wrench
4. Pin wrench

8-31. A lens cell that has 64 threads per inch and is 1/2 inch deep has burred threads which can be restored by using

1. lapping compound
2. a 32-pitch inside thread chaser
3. a 64-pitch outside thread chaser
4. a 64-pitch inside thread chaser

8-32. Thread chaser sets are available in sizes from

1. 5 threads to 20 threads per inch
2. 8 threads to 40 threads per inch
3. 3 threads to 80 threads per inch
4. 4 threads to 80 threads per inch

8-33. The outside red scale of the Geneva lens measure is graduated to read

1. counterclockwise in quarters from 0 to +17 diopters
2. clockwise in quarters from 0 to +17 diopters
3. counterclockwise in quarters from 0 to -17 diopters
4. clockwise in quarters from 0 to -17 diopters

8-34. A crown glass lens has one surface reading +9 and the other reading -3 as obtained with a Geneva lens measure. What is the dioptric value of the lens?

1. +6
2. +12
3. -6
4. -12

8-35. The dioptric strength of one lens is +1.46 and the other lens has a dioptric strength of -1.46. What is the total dioptric strength of the lens?

1. 0.87
2. 0.66
3. 4.64
4. 4.11

8-36. What is the sum of +8 plus -8?

1. 0
2. -8
3. +8
4. 16

Learning Objective: Indicate the procedure for disassembling optical instruments. Textbook pages 7-14 through 7-18.

8-37. You are preparing to disassemble an instrument that contains 3 psi internal pressure. What is the correct sequence?

1. Prepare the work space, clean the outside of the instrument, and release gas pressure
2. Prepare the work space, follow the disassembly procedure, and perform casualty analysis
3. Reduce gas pressure, clean the instrument, and prepare the work space
4. Clean the outside of the instrument, prepare the work space, and use gas pressure to break the seal of the instrument

8-38. When disassembling an optical instrument, what should you do if you find missing assembly marks?

1. Get another part with the assembly mark on it
2. Make appropriate marks of your own
3. Continue disassembling and mark when you begin assembly
4. Check the factory manual for the next step

8-39. What should you use to mark the function of the optical element?

1. Hard-lead pencil or an instant-drying marking pen
2. Soft-lead pencil or an instant-drying marking pen
3. Hard-lead pencil or a slow-drying marking pen
4. Soft-lead pencil or a slow-drying marking pen

8-40. While disassembling an unfamiliar instrument, you feel that markings on the edge of the lens do not match the correct placement of that lens. What should you do?

1. Study the optical diagram for that instrument
2. Use a Geneva lens measure to compare readings you make with the optical diagram
3. Both 1 and 2 above
4. Make your own markings on the edge of the lens

456

8-41. Which of these combinations of metals will cause an Opticalman the most trouble at disassembly?

1. Steel and steel
2. Aluminum and aluminum
3. Aluminum and steel
4. Aluminum and brass

8-42. What lubricant should you use to loosen frozen parts in optical instruments?

1. 30W oil
2. 10-30W oil
3. Vaseline
4. Penetrating oil

8-43. If mechanical components of an instrument will not separate after you have used heat, tapping, or penetrating oil, what should you do next?

1. Support the instrument and use impact
2. Cut or break the least expensive components away
3. Apply more penetrating oil and use impact
4. Use more heat and apply a steadily increasing pressure

8-44. You can soften shellac on the threads of the mount and the edge of the ring with

1. lacquer thinner or alcohol
2. alcohol or penetrating oil
3. penetrating oil or lacquer thinner
4. soap solution or alcohol

8-45. The retainer rings and lens mounts of an optical instrument may be difficult to remove because of which of the following factors?

1. Threads being frozen in place
2. Setscrews hidden by sealing compound
3. Setscrews with stripped slots
4. All of the above problems

8-46. Since uneven pressure can shear cemented optical elements apart, how should you remove a compound lens from its mount?

1. By use of penetrating oil
2. By use of heat
3. By a combination of heat and pressure
4. By using a lens chuck and cleaning holder

8-47. Canada balsam that cements the elements of compound lenses together is softened at a temperature of

1. 90° to 105°F
2. 105° to 120°F
3. 125° to 140°F
4. 140° to 160°F

8-48. Which of the following materials should be used to protect a lens removed from its mount?

1. Newsprint
2. Lens tissue
3. Paper toweling
4. Lightly oiled cloth

8-49. When you cannot push a lens out from the back, what should you use to grip the lens?

1. Small tweezers
2. Small suction cup
3. Scotch tape
4. Adhesive tape

8-50. How should you loosen a cocked lens?

1. Untwist the lens
2. Heat the lens and then remove the twist
3. Tap lightly on the edge of the mount on the side where it is stuck
4. Tap lightly on the edge of the mount opposite the side where it is stuck

---

Learning Objective: Recognize the procedure used to repair optical instruments. Textbook pages 7-18 through 7-21.

8-51. After disassembly, which of the following should be done first in overhauling an optical instrument?

1. Identify all parts
2. Clean the mechanical parts
3. Fill out a casualty analysis sheet
4. Clean the optical parts

8-52. If your shop does not have a cleaning machine, what should you use to clean mechanical instrument parts?

1. A soft-bristled brush
2. A hard-bristled brush
3. A hard rag
4. A soft rag

8-53. Which of the following is NOT a repair category for instrument parts?

1. Design of new parts
2. Repair of old parts
3. Use of a new part from stock
4. Making and refitting a new part

8-54. The blueprint for an instrument specifies a 4-48 screw in a certain location. If the tapped hole is badly damaged, what should you do?

1. Force a 5-44 screw in the hole
2. Clean the threads with a 5-44 tap and solder the screw on the hole
3. Plug the hole, solder the plug, and then drill and retap to 4-48
4. Drill the hole and retap to two or three sizes larger

8-55. What is the first thing you should try to do when you have to make a new part?

1. Find the blueprint
2. Use the old part as a sample
3. Match the material of the old part
4. Use the material specified on the blueprint

8-56. If you cannot find the cause for a malfunctioning part, what should you do first?

1. Make a trial assembly
2. Clean the mating parts
3. Check for proper clearance
4. Check for improper assembly

8-57. If there is not enough clearance on a tapered sleeve bearing, you should first

1. put a solution of pumice and clock oil on the part
2. work the parts back and forth
3. disassemble the parts
4. lubricate the parts with the proper lubricant

8-58. Prussian blue is used by an Opticalman to

1. lap in binding parts
2. find high spots on bearings
3. lubricate tight bearings
4. remove corrosion from bearing surfaces

8-59. To remove excess metal from a sliding-surface bearing, what kind of motion should you use to rub a mixture of pumice and clock oil on the bearing?

1. Straight up and down
2. Circular
3. Rectangular
4. Sweeping figure-eight

Learning Objective: Identify the tasks in joining metals by soldering and brazing. Textbook pages 7-21 through 7-24.

8-60. Which of the following publications offers detailed steps for soft soldering?

1. Tools and Their Uses, NAVEDTRA 10085 Series
2. Blueprint Reading and Sketching, NAVEDTRA 10077 Series
3. Basic Machines, NAVEDTRA 91230 Series
4. Basic Military Requirements, NAVEDTRA 10054-D Series

8-61. What is the most critical part of silver soldering and brazing?

1. The tip used
2. The control of heat
3. Where to apply heat
4. How to apply heat

8-62. What size soldering tip is used for heating large areas?

1. Medium bulb or medium velocity
2. Bulbous or low velocity
3. Swaged or high velocity
4. Bulbous or high velocity

8-63. Why does copper require a longer application of heat than steel?

1. Molecules are closer together in copper
2. Molecules are farther apart in copper
3. Heat flows from copper more quickly
4. Heat flows into copper more quickly

8-64. A flux used for brazing or silver soldering serves to

1. reduce the amount of heat required to join the parts
2. form oxides which aid the soldering or brazing process
3. prevent the formation of oxides which may hinder the joining of metals
4. clean parts to be joined by brazing or silver soldering

8-65. Cast iron components can be joined by

1. silver soldering only
2. brazing or silver soldering only
3. brazing, silver soldering, or soft soldering
4. brazing only

8-66. Flux should be applied to the joint area as soon as

1. the base metal becomes red hot
2. the filler metal starts to melt
3. the joint area surfaces have been cleaned
4. the joint is hot enough to melt the flux

8-67. If two pieces of metal contact each other, you can heat them both by applying heat to one of them. The second piece of metal is heated by

1. convection
2. conduction
3. radiation
4. polarization

8-68. In the stick-feed method, what determines when both parts are properly heated and when to feed the filler metal?

1. A meter
2. The color of the metals
3. A timer
4. The judgment of the worker

8-69. What will overheating do in the stick-feed method?

1. Flush the joint
2. Drive the flux back in
3. Burn out the flux
4. Remove the flux residue

Assignment 9

Maintenance Procedures - Part I (Continued)

Textbook Assignment: Pages 7-24 through 7-35

Learning Objective: Identify the types of metals and the properties of metals. Textbook pages 7-24 through 7-27.

9-1. Pig iron falls into which of the two general classifications of metals?

1. Ferrous
2. Nonferrous
3. Cast
4. Structural

9-2. The physical properties of a metal include

1. weight, electrical resistance, and corrosion resistance
2. magnetic influence, conduction, and density
3. color, wear resistance, and reaction to chemicals
4. elastic conductivity, weight, and magnetic influence

In Items 9-3 through 9-6 match the description of the metal in column A with the property of the metal in column B.

A. Description	B. Property of Metal
9-3. Ability to be drawn into wire	1. Ductility
9-4. Resistance to scratching, denting, and cutting	2. Hardness
9-5. Ability to be rolled into sheets	3. Malleability
9-6. Resistance to shock loading	4. Toughness

9-7. Which property of a metal resists forces that tend to pull it apart?

1. Toughness
2. Tensile strength
3. Hardness
4. Ductile strength

9-8. Which property of metal protects against effects of air?

1. Ductility
2. Tensile strength
3. Malleability
4. Corrosion resistance

9-9. Any iron in which the carbon content exceeds 1.7% is called

1. pig iron
2. cast iron
3. ingot iron
4. wrought iron

9-10. Cast iron has high

1. compressive strength
2. ductility
3. malleability
4. impact strength

9-11. What is the source of steel?

1. Cast iron
2. Pig iron
3. Ingot iron
4. Wrought iron

9-12. What kind of steel is used when structural strength is of little matter?

1. Mild
2. Medium
3. Stainless
4. Special treated

9-13. What kind of steel is generally designated by a percentage of chromium and nickel?

1. Mild
2. Medium
3. Stainless
4. Special treated

9-14. What is the main ingredient in Monel?

1. Nickel
2. Copper
3. Iron
4. Manganese

9-15. An acceptable substitute for steel under corrosive conditions is

1. bronze
2. brass
3. Monel
4. aluminum

Learning Objective: Recognize the types of heattreating, such as annealing, normalizing, hardening, tempering, and stress relieving. Textbook pages 7-27 through 7-29.

9-16. Other than alloying, what process is used to improve a physical or mechanical property of a metal?

1. Molding
2. Heat treatment
3. Purifying
4. Machining

9-17. Which of these metals can NOT be tempered?

1. Carbon steel
2. Wrought iron
3. Ingot iron
4. Copper

9-18. What are the most important factors of heat treatment?

1. Time and temperature
2. Purity and time
3. Atmosphere and time
4. Temperature and oxygen content

9-19. Which of these alloys requires the highest annealing temperature?

1. Nickel chromium
2. Copper
3. Cast iron
4. Aluminum

9-20. How does normalizing differ from annealing?

1. Normalizing is for almost all metals
2. Annealing is for ferrous metals alone
3. Normalizing is for nonferrous metals alone
4. Annealing is for almost all metals

9-21. When a high carbon steel is to be hardened, which of these heattreating processes should be applied first?

1. Annealing
2. Cooling
3. Tempering
4. Normalizing

9-22. What treatment requires that metal be heated, soaked, and slowly cooled in air?

1. Annealing
2. Normalizing
3. Hardening
4. Tempering

9-23. When steel is cooled more rapidly than specified, there is a risk of

1. destroying the alloying elements
2. overheating the quenching medium
3. annealing the steel
4. cracking the steel

9-24. To be hardened, plain carbon steel has to be cooled from red hot to a temperature of less than 1000°F in less than 1 second. What is done to increase the time?

1. Water is used as a quenching medium
2. Oil is used as a quenching medium
3. Alloys are added to the steel
4. Temperatures of the quenching mediums are changed

9-25. The process of reducing the brittleness produced during a hardening operation is called either tempering or

1. stress relieving
2. carburizing
3. normalizing
4. drawing

461

9-26. In which heat treatment are temperatures below the red hot point?

1. Tempering
2. Annealing
3. Normalizing
4. Hardening

9-27. What is the difference, if any, between tempering and toughening?

1. Toughening is done at lower temperatures than tempering
2. Temperatures used for toughening are slightly higher than those used for tempering
3. Toughening requires heat and hammering
4. There is no difference

9-28. What physical property of metal is sacrificed in tempering?

1. Brittleness
2. Hardness
3. Toughness
4. Ductility

9-29. Which of these tools requires the highest tempering temperature?

1. Drift pins and punches
2. Twist drills
3. Taps and dies
4. Machine cutting tools

9-30. What is the sequence of steps used in hardening and tempering chisels?

1. Harden, quench, polish, and temper
2. Polish, harden, quench, and temper
3. Temper, quench, polish, and harden
4. Quench, harden, polish, and temper

9-31. If a chisel is unmarked, what is a reasonable assumption?

1. It is made from special alloys
2. It is oil-hardened
3. It is water-hardened
4. It does not have to be tempered

9-32. In stress relieving, what is the top cooling rate per hour for any metal?

1. 250°F
2. 200°F
3. 300°F
4. 400°F

9-33. In stress relieving, how does the heating rate compare with the cooling rate?

1. The cooling rate is less than one-half the heating rate
2. The heating rate is less than one-half the cooling rate
3. The cooling and heating rates are the same for the first hour of treatment
4. The cooling rate is always faster than the heating rate

9-34. Which of these metals requires the highest temperature in stress relieving?

1. Stainless steel
2. Monel
3. Chromium-molybdenum steel
4. Carbon-molybdenum steel

Learning Objective: Identify the steps in cleaning optical instruments before they are painted, and the safety precautions used with chemicals necessary to the cleaning processes. Textbook pages 7-29 through 7-32.

9-35. If mechanical parts of an instrument are NOT thoroughly cleaned and corrosion free before painting, what will happen to the paint?

1. The paint will not dry
2. The paint will dry too rapidly
3. The paint will not adhere to the parts
4. The paint will cover any defective areas

9-36. Corrosion can be removed from steel by a

1. hot sulfuric acid solution
2. warm sulfuric acid solution
3. warm 10% lye solution
4. commercial paint remover

9-37. If bright spots are on brass parts before corrosion removal, what is the probable cause?

1. The parts had been dipped in a lye solution
2. The parts had been protected with paint remover
3. The parts had been protected with clear lacquer
4. The parts had been dipped in an acid solution

9-38. Corrosion removal compounds should NOT be used to remove corrosion from which of the following parts?

1. Large castings
2. Small polished parts
3. Aluminum housings
4. Bearing surfaces

9-39. When using a power-driven wire brush, always wear

1. glasses
2. gloves
3. goggles
4. ear plugs

9-40. Which of the following methods is the proper use of a buffing wheel?

1. Use light pressure, a polishing compound, and a steady movement
2. Use small pieces, a grinding compound, and a heavy pressure
3. Use little movement, a low speed, and a polishing compound
4. Use high temperatures, fast speeds, and small pieces

9-41. A fine, hand held wire brush is especially useful for removing corrosion from

1. painted surfaces
2. delicate parts
3. outside edges
4. rough casting

9-42. What should you do to put a high polish on a small, round instrument part?

1. Place the part in a padded vise and use fine emery cloth to polish the part
2. Hold the part in your hand and use a buffing wheel
3. Place the part in a lathe collet and use fine sandpaper
4. Place the part in a lathe collet and use crocus cloth

9-43. Which of these statements about the use of chemicals in an optical shop is/are true?

1. Chemicals should be considered dangerous
2. Proper attention to safety precautions can prevent injury
3. Even if you are familiar with a certain chemical, you should read the directions for its use
4. All of the above

9-44. What precaution should you observe when diluting acids?

1. Pour acid and water together into a separate container
2. Add water to acid slowly with an eyedropper
3. Pour acid into the water slowly
4. Heat the acid to the boiling point and then add water

9-45. Which of these statements applies to acids and bases?

1. Acids and bases neutralize each other
2. Acids can burn your skin while bases are safe to handle
3. Lime water will neutralize any alkali
4. Vinegar is an effective eyewash for acid burns

9-46. What does an emetic do?

1. Makes you vomit
2. Makes you cry
3. Makes you resume breathing
4. Makes you sweat

9-47. What is a fast, usually available, easy to remember emetic for acetic acid?

1. A tablespoon of salt in a glass of water
2. Any amount of vinegar and water
3. Soap
4. Alkali

9-48. Milk is a good antidote for which of the following types of poisoning?

1. Denatured alcoholic and alkalies
2. Acetic acid
3. Nitric acid
4. Hydrochloric and phosphoric acid

Learning Objective: Identify the procedures used to prepare surfaces for painting, such as paint removal; indicate the types of paint an Opticalman needs to know and the steps of preparing paint for use, the steps of painting optical instruments, and the baking procedure. Textbook pages 7-32 through 7-35.

9-49. After using a commercial paint remover, why should you scrub a part with strong soap and water?

1. To remove traces of solvent from holes or corners
2. To remove all traces of paint left on the part
3. To rough up the surface of the part
4. To remove any waxy residue from the part

9-50. What type of paint is used on eyepiece focusing rings?

1. Dull, flat paint
2. Wrinkle-finish paint
3. Semigloss paint
4. High gloss paint

9-51. If it is necessary to paint the inside of an instrument, what type of paint should you use?

1. Flat black enamel
2. Semigloss enamel
3. Black wrinkle
4. Glossy enamel or lacquer

9-52. Why should you NEVER cover enamel with lacquer?

1. The mixture brings on corrosion
2. The two serve the same purpose
3. Lacquer loosens enamel and makes it blister
4. Enamel loosens lacquer and makes it blister

9-53. What is the outstanding feature of lacquers?

1. They are abundant
2. They are economical
3. They are durable
4. They are quick drying

9-54. When preparing paint for spraying, you can avoid the possibility of lumps or dirt by

1. stirring the paint thoroughly
2. allowing the paint to settle before spraying
3. straining the paint before putting it in the spray gun
4. discarding leftover paint to avoid contamination

9-55. When paint is thoroughly stirred prior to painting, you can expect the finish to be

1. durable
2. uniformly rough
3. evenly colored
4. too thin

9-56. Paint and thinner stored in a suitable locker should be kept at temperatures between

1. 75° and 30°F
2. 100° and 32°F
3. 95° and 0°F
4. 95° and 35°F

9-57. What is the primary reason for painting external metal parts of optical instruments?

1. To kill reflections
2. To control refractions
3. To protect from rust and corrosion
4. To improve appearance

9-58. When a spray gun is covered with old paint, what should you do?

1. Coat all surfaces with paint remover and then rinse and dry the gun
2. Soak the gun in lacquer thinner and clean the gaskets with paint remover
3. Lubricate the gaskets and thin the paint
4. Use lacquer thinner on the gaskets and paint remover on the metal part

9-59. Small instrument parts are best painted by adjusting the spray to provide a

1. dense cone spray
2. fine horizontal fan spray
3. light cone spray
4. dense vertical fan spray

9-60. What way of using the spray gun will result in a good-looking, durable paint job?

1. Use a vertical fan, spray, hold the gun 10 inches from the work, and be careful not to overlap the paint
2. Use a cone-shaped spray, hold the gun 10 inches from the work, and paint the edges first
3. Adjust the spray to suit the shape and size of the work, hold the gun 10 inches from the work, and move slowly to assure a heavy first coat
4. Adjust the spray to suit the shape and size of the work, hold the gun 10 inches from the work, and cover the preceding lap with half the next lap

4S1

9-61. When should a spray gun be cleaned?

1. Before starting the day's work
2. After the last use for the day
3. After each person uses the gun
4. Whenever the paint cup is empty

9-62. A good rule of thumb for baking paint is to bake for

1. 3 hours at 250°F
2. 4 hours at 200°F
3. 2 1/2 hours at 250°F
4. 3 hours at 350°F

9-63. What is the function of monofill?

1. To make masking tape easier to remove after baking
2. To make masking tape stick better during baking
3. To fill in and accentuate engraved index lines and numbers
4. To improve the appearance of the paint after baking

9-64. Which of the following is the most likely cause for a paint finish to refuse to dry?

1. Paint too thin
2. Paint too lumpy
3. Spray gun or air line dirty
4. Oil or grease in the spray gun air supply

9-65. If your paint finish has circular markings, what is the probable cause?

1. A spray too fine
2. Air in the airhose
3. Water in the airhose
4. A dirty spraygun or airline

9-66. A grainy finish on a painted instrument indicates that

1. a lap had started to dry before the next lap was sprayed
2. the gun was too close to the work
3. dirt or lint was on the work
4. the spray was too fine

9-67. A sagging paint finish is generally caused by

1. thinning the paint too much
2. oil on the work
3. moving the gun too slowly
4. lumps in the paint

9-68. All EXCEPT which of the following factors could cause a paint finish to show an orange-peel effect?

1. Paint was too thick
2. Paint was too thin
3. Spray was too fine
4. Gun was held too far from the work

Assignment 10

Maintenance Procedures - Part I (Continued); Maintenance Procedures - Part II

Textbook Assignment: Pages 7-35 through 8-12

Learning Objective: Recognize the proper materials and techniques for cleaning and cementing lenses. Textbook pages 7-35 through 7-40.

10-1. What is selvyt cloth used for?

1. Cleaning optics
2. Lubricating mechanical gear
3. Spraying equipment
4. Touchup work

10-2. Why should you make your own swabs rather than use the already made Q-tips?

1. Q-tips are too expensive
2. Q-tips use an adhesive that dissolves in acetone
3. Q-tips will not hold acetone
4. Q-tips leave lint

10-3. What should you use to clean large optical elements effectively?

1. Several sheets of folded lens tissues dampened with acetone
2. Cotton on lens tissue swabs dampened with solvent
3. Solvent, soap and water, and camel hair brushes
4. Several sheets of lens tissue dampened with alcohol and acetone

10-4. Which of the following procedures should you use when cleaning lenses?

1. Preclean the lens with soap and water so final cleaning can be done in less than 20 seconds
2. Rub the lens vigorously with a pad or swab to loosen any dirt on the lens surface
3. Change pads or swabs frequently to avoid leaving a film on the optics being cleaned
4. Move the swab in circles, starting in the center of a lens, so lint and dirt will move to the edges

10-5. Most lenses are air-spaced if their diameter is or exceeds

1. 1 in.
2. 1 1/2 in.
3. 2 in.
4. 2 1/2 in.

10-6. Why are some lenses in an optical system cemented?

1. To improve light transmission through the instrument
2. To make mounting of the elements easier
3. To protect special types of brittle glass
4. To make disassembly of the instrument easier

10-7. What is the disadvantage of a soft glass used alone as a lens?

1. Inadequate reflection
2. Inadequate refraction
3. Quickly deteriorates
4. Turns hard under use

10-8. Using ultraviolet light, how can you tell if lenses have been cemented together with thermosetting plastic?

1. They will be opaque
2. The lenses change color
3. Little or no fluorescence will appear
4. Considerable fluorescence will appear

10-9. How can you tell if the hotplate is too hot when cementing lenses?

1. Check the dial on the hotplate
2. Watch the asbestos for signs of scorching
3. Watch the lens for discoloration
4. Watch the black paper for signs of scorching

456

10-10. What should you do if lenses do not separate when heated to 300°F?

1. Reject them
2. Raise the temperature
3. Lower the temperature
4. Insert a single-edge razor blade between them

10-11. How should you proceed to recement lenses?

1. Put a little balsam on the convex element, pick up the positive element with your tweezers, and join the two elements
2. Put a little balsam on the concave element and a little on the other element and then join the two elements
3. Put a little balsam on the concave element, pick up the positive element with your tweezers, and join them
4. Join them first for fit and then use the balsam and tweezers to rejoin them

10-12. When the elements of a lens have been recemented, why should they be worked together?

1. To remove excess cement
2. To align the axes of the elements
3. To remove eccentricity
4. To eliminate bubbles

10-13. The chuck jaws on a lens-centering instrument grip the

1. lower telescope
2. positive element
3. negative element
4. combined elements

10-14. Eccentricity in a freshly cemented lens is eliminated by moving the

1. crossline of the upper telescope
2. crossline of the lower telescope
3. negative element in the lens chuck
4. positive element against the negative element

Learning Objective: Recognize the steps of reassembly in replacing lenses or prism and identify common risks in reassembly. Textbook pages 8-1 and 8-2.

10-15. What is the first thing to do in the reassembly of lenses?

1. Get your tools ready
2. Get your parts ready and on hand
3. Remove dirt and foreign matter from the lens cells and body tube
4. Blow lint out the body tube

10-16. How can you clean the inside of a lens cell that is long or hard to clean?

1. Force air through the cell
2. Tap the outside with a small fiber mallet
3. Use a long-handled camel's hair brush
4. Purge the inside with a strong stream of water

10-17. What happens to the particles cleaned from the inside of a cell?

1. They are carried away with the forced air
2. They stick to the masking tape you placed over the open end
3. They collect on the camel's hair brush
4. They are carried away with the stream of water

10-18. How should you protect clean optics?

1. Spray a protective solution on them
2. Dip them in a lint repellent
3. Wrap them in lens tissue
4. Install them right away

10-19. How do you remove lint from the lens tissue from lenses?

1. Wash it off with the recommended cleaner
2. Wipe it off with a soft cloth
3. Pick it off with fine tweezers
4. Blow it off with an air bulb

10-20. How do you avoid fingerprints on the edge of a lens?

1. Hold the lens by its edges
2. Hold the lens on its retainer ring
3. Seize the lens by using lens tissue
4. Use a suction cup

10-21. What type of damage do you risk if you overtighten a retainer?

1. Distortion
2. Strain
3. Poor collimation
4. Impossible collimation

10-22. A shifting prism after reassembly is caused by a

1. prism in the wrong sequence
2. missing prism mount
3. prism collar too tight
4. prism collar too loose

10-23. In a prism-erecting system, how must the prisms be oriented to avoid lean?

1. 45° to each other
2. 60° to each other
3. 75° to each other
4. 90° to each other

10-24. If you have a porro prism cluster that is out of alignment by 1 1/2°, how much lean will you have as you view a target through the cluster?

1. 0.5°
2. 1.5°
3. 3.0°
4. 4.0°

10-25. How can you avoid lean during reassembly of a prism?

1. Use the adjustment provided by the designer
2. Replace the collar
3. Select a smaller collar
4. Choose a larger collar

10-26. What unusual ability must you have if you are to remove lean from a prism cluster?

1. Patience
2. Vertigo
3. Seeing two different objects at the same time
4. Imagining the horizontal to be vertical

10-27. What is the risk in trying to remove lean from a cocked prism?

1. Chipped prism
2. Reversed prism
3. Cracked prism
4. Distorted prism

Learning Objective: Identify the details of assembling mechanical parts. Textbook pages 8-2 and 8-3.

10-28. As you reassemble optical instruments, you should do which of the following?

1. Align assembly marks
2. Keep all openings closed when not in use
3. Do not force parts together
4. Do all of the above

10-29. During reassembly you run up against two parts that bind. What should be your next step?

1. Begin reassembly all over
2. Check with a senior OM
3. Find the cause of the bind
4. Use slightly more than finger pressure to overcome the bind

10-30. Adjustments always seem to be needed while you are assembling an instrument. When should you try to make these adjustments?

1. Before final reassembly
2. During collimation
3. During reassembly
4. After collimation

10-31. Threads on retaining rings, lens mounts, and the like are fine and can be cross-threaded with little effort. How can you avoid this hazard?

1. Seat the threads in a clockwise manner gently
2. Use no more than thumb pressure to seat the threads in a clockwise manner
3. Use no pressure as you rotate the thread in a clockwise direction
4. Turn them in a counterclockwise direction to click into place

10-32. To prevent corrosion, what antiseize compound should you use on external screw threads and threaded portions of body tubes?

1. Fine grease
2. Silicone grease
3. Machine oil
4. Graphite powder

10-33. Why is the antiseize compound in the preceding question the best one to use?

1. It is cheap and it lasts
2. It is always available
3. It won't run and it prevents corrosion
4. It is the only lubricant allowed on a lens retainer ring

10-34. What is the definition of collimation?

1. The final step in the overhaul and repair of an optical instrument
2. The proper application of an optical instrument
3. The alignment of the optical axis of an instrument with its mechanical axis
4. The target and crossline are placed in perfect focus

Learning Objective: Identify the elements of collimation and the collimation techniques applied to different instruments. Textbook pages 8-3 through 8-10.

10-35. What part of the collimator in figure 8-2 of the textbook is optical?

1. Base
2. Keyway
3. Telescope
4. Telescope support

10-36. The collimator shown in figure 8-2 of the text is NOT designed for use with which of the following instruments?

1. Large telescopes
2. Small telescopes
3. Gunsights
4. Navigational instruments

10-37. What holds the collimator telescope support aligned with the base?

1. V-block
2. Square keys
3. Keyway
4. Support fixtures

10-38. The auxiliary support fixtures in figure 8-3 of the textbook fit the Mk 4, Mod

1. 1 collimator
2. 2 collimator
3. 3 collimator
4. 0 collimator

10-39. The mounting stand in figure 8-6 of the textbook fits which of the following collimators?

1. Mk 13
2. Mk 7
3. Mk 5
4. Mk 4

10-40. Which collimator is used only for binoculars?

1. Mk 4, Mod 0
2. Mk 5
3. Mk 9
4. Mk 13

10-41. How many telescopes are on the Mk 9 collimator?

1. Six
2. Two
3. Eight
4. Nine

10-42. How many collimator telescopes on the Mk 9 are mounted at 0°?

1. One
2. Two
3. Three
4. Four

10-43. Which telescope is used with the Mk 9 collimator?

1. Mk 13
2. Mk 9
3. Mk 5 Mod 0
4. Mk 8 Mod 1

10-44. In which of the following publications will you find more details on collimators than this text offers?

1. NAVTRA 10206-A, Opticalman 1&C
2. OP 1417, Collimators for Optical Instruments
3. NAVEDTRA 10052 Series, Bibliography for Advancement Study
4. The pertinent Personal Qualification Standard

10-45. What unique problems exist with collimation of submarine periscopes?

1. Length of the instrument and the need for an adjustable target
2. Skill of the OM and number of OM's
3. Availability of submarine periscopes and frequency of collimation
4. Cost and secrecy of submarine periscope collimation

10-46. What is the most common tool used by an Opticalman to adjust most instruments?

1. Auxiliary telescope
2. Mk 5 collimator
3. MK 9 collimator
4. Mk 13 collimator

10-47. What is the magnification of the auxiliary telescope?

1. 6X
2. 5X
3. 3X
4. 4X

10-48. What is the main purpose of the auxiliary telescope?

1. To correct for eye defects in the repairman
2. To reduce magnification
3. To determine one's dioptric setting
4. To adjust an optical system

10-49. To get the best results in finding the dioptric setting of your eyes, take five readings and use the

1. average of the results
2. most frequent reading
3. last reading
4. third reading

10-50. Once you have found the dioptric setting of your eyes, under what circumstances should you change the setting?

1. When setting a focusing eyepiece to zero diopters
2. When setting a fixed eyepiece to zero diopters
3. When eye strain or fatigue has changed your eye's characteristics
4. When using a misaligned collimator

10-51. An auxiliary telescope is suitable for doing all but which of the following?

1. Checking for parallax and setting fixed-type and focusing eyepieces
2. Increasing the power of another telescope
3. Use as a substitute sextant telescope
4. Collimating hand held binoculars with the aid of prism attachment

10-52. When collimating 7 X 50 binoculars with an auxiliary telescope, what will be the magnification of the collimator image?

1. 3X
2. 7X
3. 18X
4. 21X

10-53. When using a machinist's square to align the Mk 4 collimator, what function are you performing?

1. Establishing parallelism between the base and the optical axis
2. Squaring the collimator crossline
3. Reforming parallax
4. Setting zero diopters

10-54. Which checking telescope is equipped with a graduated dial and a vernier index?

1. Mk 7
2. Mk 8
3. Mk 9
4. Mk 13

Learning Objective: Recognize the procedures of collimation. Textbook pages 8-10 through 8-12.

10-55. Which of these operations should you perform first in collimating optical instruments?

1. Set the zero diopters
2. Shim or scrape the mounting
3. Remove parallax
4. Square and superimpose the crossline

10-56. Which of these operations should you perform last in collimating optical instruments?

1. Set the zero diopters
2. Shim or scrape the mounting
3. Remove parallax
4. Square and superimpose the crossline

10-57. Which instrument is required to check for parallax?

1. Auxiliary telescope
2. Mk 7 checking telescope
3. Parallax meter
4. Dynameter

10-58. If the instrument's crossline came into focus at +3 diopters on the diopter scale and the collimator's crossline came into focus at -4 diopters on the diopter scale, what is the total amount of parallax?

1. +7 diopters
2. -7 diopters
3. +3 diopters
4. -4 diopters

10-59. If the collimator's crossline comes into focus after the instrument's crossline, you should move the

1. instrument's crossline away from the objective
2. objective lens toward the collimator objective
3. collimator toward the crossline
4. objective toward the crossline or the crossline toward the objective

10-60. How much parallax is normally allowed in an optical instrument?

1. Extensive
2. Moderate
3. Slight
4. None

10-61. What part has to be loosened to square the instrument crossline?

1. Objective lens mount
2. Crossline retainer ring
3. Crossline lens mount
4. Eccentric rings

10-62. What is the most common means of superimposing the crosslines?

1. Shift prisms
2. Adjust screws
3. Use eccentric objective mounts
4. Use eccentric objective lens

10-63. After having superimposed the crossline, you must recheck for

1. zero diopters
2. squareness of the crossline
3. lean
4. parallax

Assignment 11

Maintenance Procedures - Part II (Continued); Machine Tool Operation

Textbook Assignment: Pages 8-12 through 9-8

Learning Objective: Identify the procedures in setting zero diopters, controlling backlash, and controlling the line of sight. Textbook page 8-13.

11-1. To set optical zero diopters with an auxiliary telescope, always focus from the

1. minus side to the plus side
2. plus side to the minus side
3. top side to the bottom side
4. bottom side to the top side

11-2. If both crosslines are in focus at +1 diopter, what happens to the final image plane?

1. It is in too far
2. It is up too high
3. It is out too far
4. It is down too low

11-3. To set zero diopters on a gunsight telescope with two erector lenses, what should you do?

1. Move the objective in or out
2. Move the near objective in the opposite direction
3. Move the front erector in the direction you want the image plane to move
4. Move the rear erector in the direction you want the image plane to move

11-4. Optical instruments that use deflection prisms or mirrors must be checked for

1. true horizontal tracking only
2. true vertical tracking only
3. mechanical backlash only
4. true horizontal tracking, true vertical tracking, and mechanical backlash

11-5. In gunsights, backlash must be held to

1. 30 seconds or less
2. 40 seconds or less
3. 50 seconds or less
4. 60 seconds or less

11-6. In gunsights what is the maximum variance allowed in the line of sight?

1. 0.25 or 0.50 minutes of arc
2. 0.25 or 0.50 seconds of arc
3. 0.50 or 0.75 minutes of arc
4. 1 or 2 minutes of arc

Learning Objective: Recognize the steps in sealing and drying optical instruments. Textbook pages 8-13 through 8-15.

11-7. Which of the following is NOT considered a designation of optical instruments?

1. Moisture-tight
2. Dust-tight
3. Gas-tight
4. Pressure-tight

In answering Items 11-8 through 11-10, match the instrument in column A with its classification in column B.

	A. Instrument	B. Classification
11-8.	Hand held binoculars	1. Moisture-tight
		2. Weather-tight
11-9.	Bridge-mounted binoculars	3. Pressure-tight
11-10.	Submarine periscope	4. Gas-tight

11-11. A pressure-tight instrument should be charged with

1. helium
2. dry nitrogen
3. oxygen
4. water-pumped nitrogen

11-12. An optical instrument dryer has what type of filtering agent?

1. Silica gel
2. Charcoal
3. Alumina powder
4. Powdered graphite

11-13. What serves as a moisture indicator in an instrument dryer?

1. Cobalt magnesium
2. Cobalt chloride
3. Sodium chloride
4. Sodium magnesium

11-14. To dry silica gel, you bake it until it becomes

1. pink
2. brown
3. red
4. blue

11-15. Silica gel should be removed from its cylinder when it turns

1. blue
2. red
3. pink
4. green

11-16. Replace silica gel when it turns

1. white
2. gray
3. green
4. brown

11-17. What color is silica gel when it holds 50% moisture?

1. Egg white
2. Pale pink
3. Crimson red
4. Water green

11-18. Silica gel saturated nearly 100% with moisture has what color?

1. Strong pink
2. Deep blue
3. Pale red
4. Leaf green

11-19. Silica gel should be baked at least

1. 1 hour
2. 2 hours
3. 3 hours
4. 4 hours

11-20. A full cylinder of inert gas contains a pressure of

1. 1500 psi
2. 1600 psi
3. 1800 psi
4. 2000 psi

11-21. For charging instruments, NEVER use a cylinder with less pressure than

1. 400 psi
2. 600 psi
3. 800 psi
4. 1000 psi

11-22. Which of the following is bad practice when you handle gas cylinders?

1. Keep cylinders secured in place
2. Return depleted cylinders
3. Bleed empty cylinders slowly
4. Returned cylinders should have 400 psi of gas left in them

---

Learning Objective: Identify the techniques used in charging optical instruments. Textbook pages 8-16 through 8-19.

11-23. Open the valve of the cylinder pressure gage only enough to indicate a

1. sudden rise in pressure
2. slow rise in pressure
3. fast rise in pressure
4. moderate rise in pressure

11-24. How much pressure from the regulator will blow out the filter and lines?

1. 5 lb
2. 7 lb
3. 8 lb
4. 9 lb

11-25. When an optical instrument is being charged, what should the gage on the instrument dryer read?

1. About 2 psi
2. About 5 psi
3. About 7 psi
4. About 400 psi

11-26. To find leaks around fittings, gaskets, screws, or the objective window, you should use which of the following tests?

1. Brush with soapsuds
2. Submerge in water
3. Charge it to 5 psi for 24 hours
4. Do all of the above

11-27. For about how long should the purging operation be repeated?

1. 10 min
2. 45 min
3. 30 min
4. 2 hr

11-28. What is the purpose of the purging operation?

1. To remove all moisture from the instrument
2. To blow out dust and dirt
3. To seal leaks
4. To establish a positive pressure inside the instrument

11-29. When you have the instrument free of moisture, replace the outlet valve screw and let the pressure on the dryer build up to about

1. 1 lb
2. 2 lb
3. 3 lb
4. 4 lb

11-30. With the cylinder valve closed, the pressure reading should drop to

1. 1 lb
2. 2 lb
3. 3 lb
4. zero

11-31. What gas is used to charge and test rangefinders?

1. Helium
2. Oxygen
3. Hydrogen
4. Nitrogen

11-32. A helium purity indicator is used to test the percentage of helium in the rangefinder after the instrument has been purged for

1. 1 hr
2. 2 hr
3. 3 hr
4. 1/2 hr

11-33. A rangefinder will seal with a pressure of

1. 5 lb
2. 2 lb
3. 7 lb
4. 10 lb

11-34. The rangefinder should be purged until the helium purity indicator shows

1. 99.9% helium
2. 98.9% helium
3. 97.5% helium
4. 95.7% helium

11-35. Always charge an instrument with helium when the inlet valve is painted

1. red
2. blue
3. gray
4. yellow

11-36. If in doubt about which type of gas to charge an instrument, use

1. nitrogen
2. oxygen
3. hydrogen
4. helium

11-37. If an inlet valve were painted orange, you would know

1. how much pressure to use
2. what type of gas to use
3. the instrument should not be purged
4. what temperature should prevail for charging

Learning Objective: Identify the principles and methods of application in grinders. Textbook pages 9-1 through 9-5.

11-38. Why should an Opticalman study machine tool operation?

1. To gain knowledge to become a machinist
2. To gain insight into the Machinist's rating
3. To gain basic knowledge of the Opticalman's profession
4. To gain ability to make needed replacement parts and tools

11-39. Of these performance factors, which is the most important for an Opticalman?

1. Get jobs out by their priority
2. Confine work to that of the Opticalman rating
3. Take time to perform the work safely
4. Reduce costs wherever possible

11-40. The removal of metal by the cutting action of an abrasive is called

1. grinding
2. polishing
3. honing
4. burnishing

11-41. What is the process of manually holding and manipulating a workpiece for grinding?

1. Carving
2. Cutting
3. Offhand grinding
4. Offhand finishing

11-42. What part of a bench grinder protects the operator from flying chips?

1. Right-hand wheel guard
2. Wheel guard mounted shield
3. Left-hand wheel guard
4. Wheel guard mount

11-43. What are the most common and most serious hazards in working with grinding machines?

1. Abrasions
2. Foreign particles in the eye
3. Cuts
4. Shocks

11-44. What are the main ingrediente of safety in using grinders?

1. Common sense and concentration
2. Speed and accuracy
3. Concentration and speed
4. Accuracy and concentration

11-45. What is the minimum distance between the toolrest and wheel face regardless of work?

1. 1/4 in.
2. 3/8 in.
3. 1/16 in.
4. 1/32 in.

11-46. What type of pressure should you use when beginning a job on a grinding wheel?

1. Heavy
2. Moderate
3. Moderate to heavy
4. Light

11-47. The bench grinder is designed to sharpen tools made of which of these metals?

1. Aluminum
2. Brass
3. Steel
4. Monel

11-48. What should you do to a bench grinier wheel clogged with metal?

1. Dress it down
2. Apply a lubricant
3. Wash it down
4. Get a new wheel

11-49. About what percentage of a grinding wheel is abrasive?

1. 50%
2. 20%
3. 30%
4. 40%

11-50. Which of these examples is a natural abrasive?

1. Aluminum oxide
2. Silicon carbide
3. Emery
4. Monel

11-51. Which abrasive should be used for grinding carbide tools?

1. Silicon carbide
2. Aluminum oxide
3. Corundum
4. Monel

11-52. The strength of the grinding wheel comes from its

1. size
2. abrasive
3. bond
4. weight

11-53. The letters A to Z are used in grinding wheels to show the

1. grade of the abrasive
2. size of the abrasive
3. weight of the abrasive
4. structure of the abrasive

11-54. The numbers 1 to 15 apply to what feature of an abrasive?

1. Grade
2. Structure
3. Size
4. Weight

11-55. How do you "sound" a grinding wheel?

1. Spin it slowly
2. Spin it fast
3. Listen as it grinds at high speed
4. Tap it lightly with a piece of hardwood and listen for the sound

11-56. In a grinding wheel installation, what is the purpose of the recessed flange?

1. To spread the pressure of the securing nut
2. To ensure even pressure on the wheel
3. To dampen the vibration between the wheel and shaft
4. To align the grinding wheel axially

11-57. What is the process of removing material from the cutting face of the wheel?

1. Cleaning
2. Dressing
3. Truing
4. Both 2 and 3 above

11-58. On bench and pedestal grinders, what is the effect, if any, if a grinding wheel is out of balance axially?

1. The grinding will be faulty
2. The wheel will wear too fast
3. The wheel will spin off its axis
4. There is no effect

11-59. How should you stand when grinding?

1. Feet together and weight shifted slightly to one foot
2. Feet spread slightly with weight evenly distributed
3. Feet spread slightly with weight shifted slightly to one foot
4. Feet together with weight evenly distributed

Learning Objective: Develop a familiarity with drill presses and identify the methods and techniques of operation of drill presses and drills found in Navy shops. Textbook pages 9-5 through 9-8.

11-60. Why is a sensitive drill press nearly always driven by a belt?

1. Belts allow more freedom of operation
2. Vibration by gearing would be undesirable
3. Belt-driven presses cost less
4. Geared drill presses are too dangerous

11-61. Sensitive drill presses are designed for drilling holes less than

1. 1 in.
2. 3/4 in.
3. 1/2 in.
4. 3/8 in.

11-62. What part of a drill allows it to advance into the work?

1. Chisel
2. Point
3. Web
4. Lip clearance

11-63. What part of a drill runs the length of the body between the flutes?

1. Shank
2. Tang
3. Web
4. Chisel

11-64. What part of a drill fits into the chuck of the drill press?

1. Shank
2. Flute
3. Body
4. Tang

11-65. In figure 9-8 of the text, what is the angle of the drill point?

1. 118°
2. 120°
3. 135°
4. 12°

11-66. If you have to drill a hard metal, how should you modify the twist drill?

1. Increase both the point angle and the lip clearance
2. Reduce the point angle and increase the lip clearance
3. Reduce both the point angle and the lip clearance
4. Increase the point angle and reduce the lip clearance

11-67. When drills are graduated in fractions of an inch, what size increment or step is used?

1. 1/64 in.
2. 1/32 in.
3. 1/16 in.
4. 1/8 in.

11-68. An Opticalman refers to a twist drill most often by its size in

1. inches
2. letters
3. numbers
4. metrics

11-69. What is the recommended cutting speed for alloy steel?

1. 50-70 fpm
2. 70-100 fpm
3. 70-150 fpm
4. 70-200 fpm

Assignment 12

Machine Tool Operation (Continued)

Textbook Assignment: Pages 9-8 through 9-33

Learning Objective: Identify drill sizes, cutting speeds, and problems in using drills. Textbook pages 9-8 through 9-10.

12-1. You have a drill with a circumference of 1 1/2 inches turning at 400 rpm. What is the cutting speed?

1. 13.08 fpm
2. 26.00 fpm
3. 39.22 fpm
4. 50.00 fpm

12-2. Having found the cutting speed in the previous problem, which type of metal are you drilling at that cutting speed?

1. Machine steel
2. Alloy steel
3. Cast iron
4. Brass

12-3. How is drill feed expressed?

1. In tenths of an inch per revolution
2. In hundredths of an inch per revolution
3. In thousandths of an inch per revolution
4. In ten-thousandths of an inch per revolution

12-4. If your drill press can operate at 550 rpm, 1500 rpm, 2100 rpm, and 2700 rpm, what speed should you select to drill brass with a 1/4-inch drill?

1. 550 rpm
2. 1500 rpm
3. 2100 rpm
4. 2700 rpm

12-5. What size drill should you use to start a 1/4-inch hole?

1. 1/8
2. 3/16
3. 1/4
4. 5/16

12-6. A drill with unequal length cutting lips produces

1. undersize holes
2. oversize holes
3. rough edges on the top of the hole
4. rough edges on the bottom of the hole

12-7. What should you do first if a drill wobbles?

1. Turn the machine on and off to check for turnout
2. Examine the drill shank
3. Clean the chuck and drill press spindle hole
4. Straighten the bent drill

12-8. What safety precaution must you observe just before you start the drill press?

1. Put on gloves
2. Put on an apron
3. Lightly touch the drill with the work
4. Put on goggles

12-9. What type of pressure is generally used for most small drilling?

1. The pressure of the drill bit alone
2. Fingertip pressure
3. Normal pressure of one hand
4. Normal pressure of two hands

478

12-10. If you hear snapping sounds while using a small drill, which of the following is usually the trouble?

1. Drill speed is too high
2. Drill speed is too low
3. Drill is dull
4. Drill has not enough lip clearance

12-11. What, if anything, should you do to the drill cutting edge when drilling brass and steel?

1. Grind it slightly flat
2. Harden it
3. Sharpen it
4. Leave it alone

12-12. What is the cure for galling?

1. Use a lubricant
2. Use no lubricant
3. Reduce the size of the drill
4. Select a bigger drill

Learning Objective: Name and find the principal parts of the engine lathe and be able to work with the lathes in Navy shops. Textbook pages 9-10 through 9-16.

12-13. In an engine lathe, longitudinal feed is movement of the cutting tool in what direction?

1. Up and down
2. In and out
3. Left and right
4. Diagonally

12-14. Lathe size is determined by

1. only the diameter of work it will swing over the bed
2. only the length of the bed
3. both the length of the bed and the diameter of work it will swing over the bed
4. diameter of material to be worked on

12-15. What is the first thing you should learn in the operation of a lathe?

1. Names and functions of main parts
2. Types of jobs to be done
3. Safety features
4. Construction features

12-16. What is the main part of the lathe bed?

1. Ways
2. Tailstock
3. Carriage
4. Headstock

12-17. Of the four ways shown in figure 9-12 of the text, which way takes most of the downward thrust?

1. 1
2. 2
3. 3
4. 4

12-18. How many speeds are obtainable with each position of the belt on the headstock pulley?

1. One
2. Two
3. Three
4. Four

12-19. When using a gear-driven headstock, what should you always do to avoid stripping gear teeth?

1. Use the clutch
2. Handle it like the transmission in a car
3. Upshift from neutral
4. Stop the lathe before shifting gears

12-20. Who should make bearing adjustments on the engine lathe?

1. An experienced lathe repairman
2. The maker of the lathe
3. An upper echelon naval repair activity
4. Contract repair and adjustment facilities

12-21. What is the main function of the tailstock?

1. To hold tapered shank drills
2. To accommodate work of varying lengths
3. To hold the dead center to support one end of the work being machined
4. To serve as a drill chuck

12-22. The dead center is held in a tapered hole in what component?

1. The handwheel
2. The spindle-adjusting knob
3. The keyway
4. The tailstock spindle

12-23. The quick-change gearbox consists mainly of a

1. cone-shaped group of change gears
2. diamond-shaped group of change gears
3. helical gear arrangement
4. spur gear arrangement

12-24. The carriage of a lathe has how many major components?

1. One
2. Two
3. Three
4. Four

In Items 12-25 through 12-27 match the functions in column A with the components in column B.

	A. Function	B. Component
12-25.	Moves the cutting tool at right angles to the ways	1. Half-nut closure lever
12-26.	Contains the gears and mechanism for controlling the movement of the carriage for longitudinal feed and thread cutting	2. Saddle
		3. Apron
		4. Cross-slide
12-27.	Engages and disengages the lead screw when cutting threads	

12-28. In the carriage assembly apron, how many positions are available on the feed change lever?

1. One
2. Two
3. Three
4. Four

Learning Objective: Recognize and be able to select and use attachments and accessories vital to successful operation of the engine lathe. Textbook pages 9-16 through 9-22.

12-29. Which lathe chuck is the most practical for general work as well as providing the most clamping power?

1. 3-jaw scroll
2. 4-jaw scroll
3. 3-jaw independent
4. 4-jaw independent

12-30. Which chuck can be used for holding only round or hexagonal work?

1. 1-jaw
2. 2-jaw
3. 3-jaw
4. 4-jaw

12-31. What is a common fault with the 3-jaw chuck?

1. Runout
2. Easily broken
3. Fast wear
4. Slow operation

12-32. What is the best chuck for holding small diameter work?

1. Drill chuck
2. Collet
3. 3-jaw
4. 4-jaw

12-33. As the carriage moves longitudinally, the taper attachment moves the cross-slide

1. longitudinally
2. laterally
3. forward
4. perpendicularly

12-34. What attachment is used to provide an intermediate support for long slender bars being machined between centers?

1. Taper attachment
2. Collet
3. Drill chuck
4. Center rest

12-35. What attachment is used to back up work of small diameter to keep it from springing under the stress of cutting?

1. Follower rest
2. Centering rest
3. Taper attachment
4. Collet

12-36. Which attachment indicates points at which the half-nuts may be engaged?

1. Carriage stop
2. Follower rest
3. Center rest
4. Thread dial indicator

12-37. Repeated measurements of the same dimension are eliminated by the use of the

1. thread dial indicator
2. center rest
3. follower rest
4. carriage stop

12-38. What device holds the work between points so it can be turned accurately on its axis?

1. Thread dial indicator
2. Lathe center
3. Follower rest
4. Center rest

12-39. How can you tell a live center from a dead center?

1. Only the dead center has a groove around the hardened tail
2. Only the dead center revolves with the work
3. Only the live center does not turn with the work
4. Only the live center has a point finished to an angle of 60°

12-40. You are machining a part that requires all finished external surfaces to run true with a hole which extends through the part. Which device will you need?

1. Mandrel
2. Center rest
3. Follower rest
4. Lathe center

Learning Objective: Identify the features and functions of cutting tools built into the lathe when it was designed, and describe the process of grinding cutting tools from tool blanks. Textbook pages 9-22 through 9-28.

12-41. Which of the following is NOT a major factor in designing and grinding a cutting tool?

1. Property of the material to be cut
2. Type of cut to be taken
3. Composition of the cutting tool
4. Design and shape of tool blanks

12-42. How does a metal-cutting tool do its job?

1. It rips the metal apart
2. It pushes the metal apart
3. It wears the metal down
4. It melts the metal

12-43. The part of the tool behind the cutting edge is called the

1. bit
2. blank
3. shank
4. rake

In Items 12-44 through 12-47 match the term in column A with the definition in column B.

	A. Term		B. Definition
12-44.	Back rake	1.	The angle at which the face of the tool is ground away with respect to the top surface of the tool bit
12-45.	Side rake	2.	The angle that the side or flank of the tool is ground so that the cutting edge leads the flank surface during cutting
12-46.	Side relief	3.	The angle at which the end surface of the tool is ground so that the end face edge of the tool clears the work being turned
12-47.	End relief	4.	The angle at which the face is ground with respect to a plane parallel with the top surface of the tool

12-48. What radius on the tool nose is satisfactory for rough turning in most optical shops?

1. 1/64 in.
2. 1/32 in.
3. 1/16 in.
4. 1/8 in.

12-49. The steps in the tool grinding procedure are:

A. Grind the end cutting edge angle, nose radius, and end relief.
B. Form the side cutting edge angle and side relief.
C. Hone the cutting surfaces with an oilstone.
D. Grind the side rake and back rake angles.

What is the correct sequence of these steps?

1. B, A, D, C
2. A, B, C, D
3. A, D, C, B
4. B, C, D, A

12-50. The rate at which the surface of the work passes the point of the cutting tool is called the

1. cutting speed
2. cutting rate
3. cutting feed
4. tool feed

12-51. What is the cutting speed for a 3-inch diameter piece turning at 100 rpm?

1. 52 fpm
2. 523 fpm
3. 78 fpm
4. 785 fpm

12-52. The amount the tool advances in each revolution of the work is the definition for

1. feed
2. work
3. input
4. cut

12-53. Feed is usually expressed in

1. hundredths of an inch per revolution of the spindle
2. thousandths of an inch per revolution of the spindle
3. tenths of an inch per revolution of the spindle
4. ten-thousandths of an inch per revolution of the spindle

12-54. If steel can be rough turned dry at 60 fpm, flooding it with a good cutting lubricant will increase its turning speed by

1. 10 fpm
2. 20 fpm
3. 30 fpm
4. 40 fpm

12-55. Which of these metals has the slowest rough cutting speed with a high-speed steel bit?

1. Aluminum
2. Brass
3. Machine steel
4. Bronze

12-56. To increase productivity when you rough parts down to size, you should

1. use the greatest depth of cut and feed per revolution that the job will allow
2. use the least depth of cut and feed per revolution that the job will allow
3. use tools that permit higher feed at the same speed
4. reduce the time to complete the job

12-57. A finish turning operation uses a higher surface speed than a rough turning operation. How much higher?

1. 25%
2. 35%
3. 50%
4. 60%

12-58. What are the main reasons for using a cutting lubricant?

1. To cool and lubricate
2. To polish and hone
3. To lubricate and moderate
4. To cool and govern

12-59. What is the recommended lubricant for threading in all steels and cast iron?

1. Kerosene mixed with oil
2. Mineral lard oil
3. 5% solution of soluble oil
4. 10% solution of soluble oil

12-60. How often should lathe ways be oiled?

1. Monthly
2. Weekly
3. Every other day
4. Daily

Learning Objective: Trace elements of lathe operation, such as mounting work, centering the work, and turning between centers. Textbook pages 9-28 and 9-29.

12-61. Before you begin to machine, study the blueprint of the piece to be made. The blueprint will tell you all EXCEPT which of the following factors?

1. Dimensions
2. Reference points
3. Best procedure
4. Size of stock needed

12-62. When more machining is to be done on round stock turned to finished size, the most practical method of holding the work is to use a

1. collet
2. lathe center
3. center rest
4. follower rest

12-63. The diameter of the countersunk hole for stock 1 1/4 to 2 inches should be

1. 1/8 in.
2. 3/16 in.
3. 1/4 in.
4. 5/16 in.

Learning Objective: Recognize the requirements and steps in setting the tool in lathe operation. Textbook pages 9-29 through 9-33.

12-64. What is likely the greatest cause of chatter in machine tooling?

1. Insufficient lubrication
2. Too little speed
3. Too much cut
4. Too much speed

12-65. If you want to reduce the diameter of a piece by .015 inch, you must remove how much from the surface?

1. .0050 in.
2. .0200 in.
3. .0075 in.
4. .0100 in.

12-66. You should take a finishing cut when the stock has been turned to within how much of the finished size?

1. 1/16 in.
2. 1/32 in.
3. 3/64 in.
4. 3/32 in.

12-67. Facing is the machining of the

1. end surfaces and shoulders of a workpiece
2. sides of a workpiece
3. top of a workpiece
4. diameter of a workpiece

12-68. For greater accuracy in obtaining a given size in finishing a face, the compound rest may be set at 30°. In this position, one-thousandth of an inch will move the tool how much into the work?

1. .0005 in.
2. .001 in.
3. .002 in.
4. .05 in.

Assignment 13

Machine Tool Operation (Continued); Optical and Navigation Equipment

Textbook Assignment: Pages 9-33 through 10-20

Learning Objective: Identify the critical steps in boring, particularly the aspects of a successful taper, and solve simple mathematical problems related to boring and tapering operations. Textbook pages 9-33 through 9-36.

13-1. When a piece of work must be reamed to exact size and the correct drill is not available, boring should be done to within how much of the finished size?

1. 1/32 in.
2. 1/64 in.
3. 3/64 in.
4. 3/32 in.

13-2. For machine operation, taper is expressed as the amount of change in diameter over what length, regardless of the length of the object?

1. 6 inches
2. 1 inch
3. 25 centimeters
4. 1 foot

13-3. Find the taper per foot of a piece 3 inches in diameter at the large end, 2 inches in diameter at the small end, and 2 inches long?

1. 6 in. TPF
2. 2 in. TPF
3. 3 in. TPF
4. 4 in. TPF

13-4. If you want to cut a 60° lathe center, you must set the compound rest at

1. 30°
2. 45°
3. 70°
4. 90°

Learning Objective: Define the terms used in describing screw threads and screw thread systems and identify the procedures used to calculate and machine screw threads. Textbook pages 9-36 through 9-40.

13-5. What type of thread is used on bolts and nuts?

1. Square
2. V-form
3. Round
4. Acme

13-6. Which type of screw thread can you use to increase mechanical advantage and provide good clamping, as in a screw jack?

1. Acme
2. Square
3. Round
4. V-form

13-7. The distance a threaded part moves in one revolution defines thread

1. lead
2. pitch
3. class
4. form

454

13-8. To what class of threads do shrink fits belong?

1. 1
2. 2
3. 3
4. 5

13-9. To cut a V-form screw thread, you need to know the width of the flat at the root of the thread, the straight depth of the thread, the slant depth of the thread, and the thread

1. pitch
2. root
3. crest
4. series

13-10. What characteristic of a thread is the basis for finding all other thread dimensions?

1. Series
2. Form
3. Pitch
4. Root

13-11. If the number of threads per inch is 12, what is the depth of the external thread?

1. 12 X 0.61343
2. 12 X 0.54127
3. 1/12 X 0.54127
4. 1/12 X 0.61343

13-12. To produce the correct thread profile, the cutting tool must be ground to

1. 45° with 0° back rake
2. 60° with 0° back rake
3. 45° with 10° back rake
4. 60° with 10° back rake

13-13. An Opticalman not very proficient at threading should always put the lathe in back gear and turn the headstock at about

1. 30 rpm
2. 45 rpm
3. 60 rpm
4. 75 rpm

13-14. To cut threads with 13 1/2 threads per inch, close the half-nuts at any

1. line on the dial
2. even-numbered line on the dial
3. odd-numbered line on the dial
4. 1/2 line on the dial

Learning Objective: Recognize the precautions applicable to safe operation of the lathe. Textbook pages 9-40 and 9-41.

13-15. When operating machine tools, what is your responsibility toward personnel observing your operation?

1. Remove personnel to a safe distance
2. Ensure that they do not distract you
3. Both 1 and 2 above
4. Notify them that you are not responsible for their safety

13-16. Which of these is/are unsafe?

1. Stopping a machine with the control switch
2. Maintaining a machine in adjustment
3. Making fine adjustments while a machine is in operation
4. All of the above

13-17. Where should gear covers and safety guards be kept?

1. Store them to keep them available
2. Remove them but for certain operations
3. Make sure they are in place
4. Use them just for novice machine operators

Learning Objective: Identify the types, purposes, and functions of milling machines and the standard equipment provided with milling machines in Navy ships. Textbook pages 9-41 through 9-46.

13-18. When the workpiece must be set up at a complex angle in relation to the axis of the spindle and to the table surface, which type of vise should be used?

1. Swivel
2. Flanged plain
3. Toolmaker's swivel
4. Toolmaker's universal

13-19. What is the purpose of the concentric circles of holes in the index plate?

1. To control rotary dynamics
2. To provide balance to the index plate
3. To convert rotary to angular value
4. To permit gaging of partial turns of the worm shaft

13-20. What is the value of the smallest graduation on the worktable shown in figure 9-60 of the text?

1. 1°
2. 1/2°
3. 1/4°
4. 0°

Learning Objective: Identify the principles and procedures of milling machine operation; recognize the various attachments, applications, and planes of movement available; and recognize milling machine safety precautions. Textbook pages 9-46 through 9-54.

13-21. In how many directions does the milling machine table move?

1. One
2. Two
3. Six
4. Four

13-22. Which method illustrated in figure 9-64 of the text is the most accurate for positioning a cutter?

1. A
2. B
3. C
4. D

13-23. Which safety precaution should you practice as you use method A in figure 9-64 of the text?

1. Insert a strip of paper between the cutter and the side of the workpiece
2. Start the cutter turning slowly
3. Move the workpiece into position as shown
4. Keep your hands clear of the cutter when using the paper

13-24. All EXCEPT which of the following is a factor in finding the correct cutter speed?

1. The harder the metal being cut, the slower the cutting speed
2. Carbide tooth cutters may be operated 50% to 100% faster than high-speed steel cutters
3. Cutters with a radial face cut more freely than those with undercut teeth
4. Sharp cutters may be run with higher speeds than dull cutters

13-25. Why do carbide tooth cutters tolerate higher speeds than high-speed steel cutters?

1. They have harder teeth
2. They have more teeth
3. They have a radial face
4. They resist heat better

13-26. Which of the following metals has the highest surface cutting speeds?

1. Brass
2. Aluminum
3. Malleable cast iron
4. Low carbon steel

13-27. What is the cutting speed of a 2 1/4-inch end mill turning at 150 rpm?

1. 88 fpm
2. 120 fpm
3. 344 fpm
4. 662 fpm

13-28. How do you reduce chatter in the milling machine during the cutting process?

1. Reduce the speed and increase the feed
2. Reduce both the speed and feed
3. Increase both the speed and feed
4. Increase the speed and reduce the feed

13-29. Which division can NOT be found in direct indexing?

1. 6
2. 8
3. 9
4. 12

13-30. If you need to divide a piece of work into eight equal parts, using rapid indexing, what is the number of holes to advance the index for each cut?

1. Six
2. Eight
3. Three
4. Four

13-31. If eight divisions are required, using plain indexing, how many complete turns of the index crank are needed for each division?

1. 5
2. 8
3. 10
4. 4

13-32. Simplify 48/72.

1. 6/9
2. 2/3
3. 3/2
4. 12/18

13-33. What is the constant when you convert degrees to minutes?

1. Time
2. Distance
3. Rate
4. 60

13-34. Convert 35°15' to minutes.

1. 35 1/4°
2. 35 1/4° X 60'
3. 2100'
4. 2115'

Learning Objective: Identify the principles of construction, disassembly, inspection, cleaning, repair and reassembly of the parallel motion protractor (PMP). Textbook pages 10-1 through 10-4.

13-35. On a parallel motion protractor (PMP) the components of the scale lock and the protractor lock are interchangeable.

13-36. PMP band covers are held between the elbow brackets and the head bracket and the fork bracket by

1. lockscrews
2. crosspins
3. friction
4. formed steel retainers

13-37. Before releasing tension on the bands of a PMP, which of the following steps should you take?

1. Unlock the protractor
2. Squeeze the band covers
3. Turn the upper and lower tubes
4. Hold the thrust screws

13-38. When the elbow bracket is disassembled, the bearings (part 70 in figure 10-2C of the text) will remain on the

1. upper and lower elbow brackets
2. elbow pulley
3. lower brake shaft
4. elbow spindle

13-39. How, if at all, are PMP bearings inspected?

1. By a visual check only
2. By rolling them with your fingers
3. By rolling them on their spindles
4. No inspection is necessary; bearings are always replaced

13-40. Which of the following defects can affect parallel motion of the PMP scale?

1. Different size pulleys
2. An eccentric pulley
3. Both 1 and 2 above
4. A loose elbow brake

13-41. What should you do to restore a broken PMP band?

1. Select a new matching band from stock
2. Break the other band, trim both to matching length, and re-weld
3. Square the broken ends, weld the break, and dress the weld
4. Dress the broken ends, overlap the band, and silver solder the band

13-42. After cleaning and painting a PMP, you should lightly lubricate all metal components.

13-43. If the scale lock and/or protractor lock is not properly positioned when locked, what action should you take?

1. Remove the "L" nut, reseat the bushing, and reseat the "L" nut
2. Remove the "L" nut, replace the bushing with a 10-32 screw and reseat the "L" nut
3. Remove the "L" nut and bushing and replace the scale lock with a 10-32 screw
4. Remove the "L" nut and bushing and shim or machine the scale lock

13-44. The final check for accuracy of a PMP involves comparing the parallelism of lines drawn with the elbow bracket in two different positions.

Learning Objective: Name and identify parts of the Navy's magnetic compass; and recognize steps in the inspection, disassembly, repair and assembly, and testing and adjustment of the magnetic compass. Textbook pages 10-4 through 10-12.

13-45. What is the purpose of the fluid in a compass bowl?

1. Increases the weight of the float assembly
2. Stabilizes the float assembly
3. Increases the effectiveness of the magnets
4. Both 2 and 3 above

13-46. What components are located on the float assembly of a magnetic compass?

1. Float, compass card, pivot, magnets
2. Compass card, magnets, expansion chamber, pivot jewel
3. Bar magnets, pivot tip, compass card, expansion chamber
4. Pivot jewel, float, compass card, magnets

13-47. The expansion chamber on a compass is always sealed and surrounded by liquid.

13-48. If a compass card is tilted and there is no bubble under the cover glass, what is the probable cause of the problem?

1. A leaking expansion chamber
2. A leaking float
3. Shifted magnets
4. Shifted compass card

13-49. While you are testing the period of a compass, the card stops in the middle of its swing. What could cause this problem?

1. The compass pivot is worn
2. The magnets are weak
3. The pivot jewel is broken
4. The expansion chamber has a leak

13-50. When removing the bezel ring from a compass, why should you loosen opposing screws?

1. To prevent breaking the bezel edge
2. To prevent spilling the compass liquid
3. To prevent warping of the compass bowl
4. To prevent breaking the cover glass

13-51. How is the expansion chamber sealed to the compass bowl?

1. A brass and a lead washer on top
2. Two lead washers
3. Two brass washers
4. A metal cover held with screws

13-52. The cover that protects the expansion chamber should be replaced in its original position to maintain the balance of the compass.

13-53. What should you do to recondition a compass pivot point?

1. Shape with a file and polish with a stone to a radius of 0.005 inch
2. Shape and polish the point with stones to a 0.005-inch radius
3. Cut the point down on a lathe and polish the point with 0.005 grit emery cloth
4. Sharpen the pivot to a needle point with an oilstone

13-54. A compass float can be tested for leaks by submerging it in water cooled to 42°F.

498

13-55. If a compass float has leaks, the leaks should not be soldered until the float is dry and the surface has been prepared.

13-56. A compass float can be balanced by adding or removing solder.

13-57. What condition(s) must be met before the cover glass can be replaced on a compass?

1. The seat for the glass must be smooth
2. The seat for the gasket must be clean and dry
3. The gasket and glass seating surfaces must be clean, flat, and smooth
4. The glass and gasket must be scraped and polished

13-58. The compass card is made concentric with the inside of the compass bowl by

1. measuring the distance from the pivot to the edge of the bowl
2. bending the compass card supports
3. adjusting the pivot eccentric nut
4. bending the pivot

13-59. In what condition is the reassembled compass when you test for leaks around the bezel ring?

1. The compass is immersed in warm water to check for bubbles
2. The bowl is completely filled and tested under a vacuum
3. The bowl is slightly pressurized to check for leaking fluid
4. The bowl is nearly full of liquid and you have a slight vacuum in the air space

13-60. Even though a compass bowl is completely filled with liquid after assembly, an air bubble may appear due to

1. temperature changes
2. a leaking float
3. trapped air in the liquid
4. a leaking expansion chamber

Learning Objective: Identify the construction features of azimuth and bearing circles, and recognize the steps in repairing and adjusting these instruments used in navigation. Textbook pages 10-13 through 10-18.

13-61. The true bearing of an object sighted with a bearing circle can be read directly from the bearing ring.

13-62. Inaccurate readings taken with an azimuth circle could be caused by which of the following errors?

1. An eccentric bearing ring
2. Improper adjustment during overhaul
3. An incorrectly leveled instrument
4. All of the above

13-63. The front sight and black mirror of an azimuth circle pivot on

1. a common friction fitted pin
2. two tapered pins attached to the penta prism box
3. two pins attached to the front sight bracket
4. dowel pins through the penta prism box

13-64. A cylindrical lens is used on the azimuth circle at

1. 90° to the rear sight vane
2. 180° to the rear sight vane
3. 120° to the rear sight vane
4. 360° to the rear sight vane

13-65. Prior to collimating an azimuth or bearing circle, the collimator stand must be levelled and the dumb line must be pointing directly at the light source.

Learning Objective: Identify the construction features of a stadimeter, and outline the procedures for repairing and adjusting the stadimeter. Textbook pages 10-18 through 10-20.

13-66. What condition of the horizon and index mirror allows for aligning the mirrors of a stadimeter parallel to each other?

1. The index and horizon mirrors can both be tipped and rotated
2. The index mirror can be tipped and the horizon mirror can be rotated
3. The two mirrors can be rotated but only the horizon mirror can be tipped
4. The two mirrors can be tipped, but only the horizon mirror can be rotated

13-67. What factor(s) affect(s) the accuracy of a stadimeter?

1. Perpendicularity of the index arm pivot axis
2. A snug fit between the index arm and frame
3. A snug fit between the carriage block and carriage screw
4. All of the above

13-68. If the index arm and carriage do not run true within 0.0005 inch, the index arm bearing set must be replaced.

Assignment 14

Optical and Navigation Equipment (Continued); Night Vision Sights and Gunsights

Textbook Assignment: Pages 10-20 through 11-12

Learning Objective: Indicate how the sextant is built, name its parts, and be able to repair and adjust this instrument. Textbook pages 10-20 through 10-23.

14-1. For what reason(s) should you NEVER remove the female center from a sextant frame?

1. The index arm will bind in the frame guide slot
2. You will not be able to re-center the bearing in the frame
3. You will not be able to make the center perpendicular to the frame
4. Both 2 and 3 above

14-2. How is the sextant worm screw held in mesh with the rack teeth?

1. By the weight of the index arm and worm frame
2. By a flat spring bearing against the end of the worm shaft
3. By spring tension between the index arm and worm frame
4. By finger pressure on the disengaging levers

14-3. Turning the micrometer drum exactly 3 4/10 revolutions will move the index arm how far?

1. 204'
2. 102'
3. 3°12'
4. 30°20'

14-4. What principle must be observed with respect to lubricant on the sextant worm and arc teeth?

1. Lubricant must be applied sparingly
2. Use light oil rather than grease
3. Lubricant does more harm than good
4. Lubricant must be renewed each overhaul

Learning Objective: Identify the parts and construction of the OOD and QM spyglasses; identify the procedure used in disassembling, repairing, reassemblying, and collimating these spyglasses. Textbook pages 10-23 through 10-29.

14-5. The OOD spyglass is made moisture tight by

1. setscrews and sealing compound
2. sealing compound and grease
3. threaded tube sections and sealing compound
4. threaded tubes, grease, setscrews and sealing compound

14-6. The positive achromatic doublet objective lens forms a real, erect, and diminished image.

14-7. The lenses used in the eyepiece of the OOD or QM glass are not interchangeable.

14-8. The focusing ring of an OOD telescope is held on the eyepiece mount by

1. a setscrew
2. two lock rings
3. two retaining rings
4. a lock ring and retaining ring

14-9. How is the focusing key of the OOD or QM spyglass secured to the eyepiece drawtube?

1. Screws and dowel pins
2. A longitudinal slot in the eyepiece mount
3. Two screws
4. Two dowel pins

14-10. Slight scratches or pitting can be tolerated on any lens in a spyglass EXCEPT the

1. collective lens
2. objective lens
3. erector lens
4. eyelens

14-11. The spyglass erector lens can be mounted either way in the optical system.

14-12. How is mechanical midthrow of the spyglass focusing mechanism set?

1. Repositioning the focusing key
2. Measuring the midpoint of eyepiece drawtube travel
3. Repositioning the diopter ring to align the 0 mark with the focusing ring index
4. Doing both 2 and 3 above

14-13. During reassembly of the OOD or QM spyglass, when is the eyepiece lubricated and reassembled?

1. When setting the midthrow position of the eyepiece
2. When adjusting the fit of the focusing key
3. After setting the position of the diaphragm and replacing the lenses
4. After setting the midthrow position of the eyepiece

14-14. A fine wire is placed behind the collective during collimation of the OOD spyglass to assist with

1. positioning the objective lens
2. removing parallax
3. setting optical 0 diopters
4. sealing the objective

14-15. Optical zero diopters is set in an OOD or QM spyglass by

1. adjusting the erector and objective
2. moving the erector the same direction the image plane must move
3. adjusting the collective and erector
4. moving the erector the opposite direction the image plane must move

---

Learning Objective: Indicate how the ship telescope and alidade are put together, and identify steps in repairing and adjusting these instruments. Textbook pages 10-29 through 10-34.

14-16. What type(s) of eyepiece(s) is/are used on the ship telescope?

1. Reversible
2. Variable power
3. Internal focusing
4. Orthoscopic or Kellner

14-17. If the objective of a ship telescope needs to be repositioned, how could this be accomplished?

1. Remove the lens and use thicker or thinner shims
2. Shift spacers from front to rear or vice versa
3. Remove the front sight vane, loosen the lockring, screw the mount in or out
4. Recement the lens elements

14-18. Which of the following components are mounted on the prism box of a ship telescope?

1. Porro prism cluster, filter assembly, and focusing assembly
2. Filter assembly and porro prism cluster
3. Eyepiece and porro prism cluster
4. Rear sight, eyepiece, and porro prism cluster

14-19. The clear filter used in a ship telescope helps to improve target contrast.

14-20. Parfocalizing the set of eyepieces used with a ship telescope is accomplished by

1. the operator
2. shimming
3. machining
4. collimation

14-21. A telescopic alidade can be used to measure the range to distant objects.

14-22. The auxiliary field of the Mk 6 or 7 alidade is seen by the operator as being

1. focused independently from the main optical system
2. superimposed on the main field of view
3. visible in the upper portion of the main field
4. visible in the lower portion of the main field

14-23. How many objective lenses are used in the Mk 6 or Mk 7 alidade optical system?

1. One
2. Two
3. Three
4. Four

14-24. If the image of the compass card is not properly aligned with the main field, what optical element in the Mk 6 or Mk 7 alidade should be adjusted?

1. The auxiliary prism
2. The main prism
3. The reticle mask
4. The auxiliary mirror

14-25. In the Mk 6 or Mk 7 alidade, if the image of the level vial is slightly out of focus, what adjustment, if any, should you make?

1. Screw the auxiliary objectives in or out
2. Reposition the main objective
3. Adjust the auxiliary erectors
4. None, no adjustment is possible

Learning Objective: Identify the construction of binoculars, ship-mounted binoculars, and boresight telescopes; and be prepared to overhaul or repair and maintain these instruments. Textbook pages 10-34 through 10-49.

14-26. What feature of hand held binoculars allows users with different inter-pupillary distances to use these instruments?

1. Widely spaced objective lenses
2. A hinge between the two telescopes
3. A porro prism erecting system
4. Focusing eyepieces

14-27. What characteristic of 7 X 50 binoculars allows use of these instruments in a variety of light conditions?

1. Large objective lenses
2. Widely separated objectives
3. Reasonably low magnification
4. Coated optics

14-28. Of the following binoculars, which is the best to use in heavy weather?

1. Mk 28
2. Mk 39
3. Mk 32

14-29. The mechanical axis of a pair of binoculars is established by the

1. hinge
2. prism clusters
3. eyepieces and objectives
4. left and right bodies

14-30. Prisms in the Mk 45 binocular can be positioned by

1. adjusting the prism locating shoes
2. shifting the prism clips
3. shifting the prism collar
4. adjusting the prism shields

14-31. Size comparison of binocular prisms is made by

1. checking the height of the reflecting surfaces of adjacent prisms
2. measuring the length of individual prisms
3. measuring the focal length of individual prisms by using a lens centering instrument
4. checking the height of entrance/emergence faces of adjacent prisms

14-32. Eyepiece cells of commonly used Navy binoculars are removed from their cover plates in the same manner.

14-33. During collimation of a pair of binoculars, you notice that the right eyepiece is 3/32 inch higher than the left when both images are in sharp focus. How can you correct this inequality?

1. Use a larger prism in the right barrel
2. Use a smaller prism in the left barrel
3. Either 1 or 2 above
4. Use a shorter focal length objective in the left barrel

14-34. Collimation of a binocular is accomplished by a combination of optical instruments to the binocular and mechanical adjustments to the collimator fixture.

14-35. What tolerances should you apply to binocular collimation?

1. 2' divergence, 2' step, 4' convergence
2. 2' convergence, 4' step, 2' divergence
3. 2' step, 4' convergence, 4' divergence
4. 0' step, 0' divergence, 0' convergence

14-36. Interpupillary adjustment of the ship binocular is accomplished by

1. rotating rhomboid prisms in opposite directions
2. rotating the eyepieces in opposite directions
3. sliding the eyepieces in opposite directions
4. using a hinge between the eyepieces

14-37. Collimation of the Mk 3, mod 2 ship binocular varies from a hand held binocular due to the method used for adjusting the objectives.

14-38. How should a boresight be used?

1. Centered in the muzzle disc, focused on a breech bar, then focused on an external target
2. Centered in the breech, focused on a muzzle disc, then focused on an internal target
3. Centered in the breech, aligned with a muzzle disc, then focused on an external target
4. Focused on a breech bar and aligned with an external target

14-39. How is the Mk 75 boresight adjusted to provide a parallax-free view of a target?

1. The objective focuses on targets between 10 feet and infinity and the eyepiece focuses the final image
2. The erectors focus on targets between 10 feet and infinity and the eyepiece focuses the final image
3. The objective focuses on targets between 6 feet and infinity and the eyepiece focuses the final image
4. The erectors focus on targets between 6 feet and infinity and the eyepiece focuses the final image

14-40. On the Mk 8 and Mk 75 boresights, what is the function of the spherical bearings?

1. To remove eccentricity between the crossline and telescope body
2. To center the objective in the boresight fixture
3. To allow adjustment of the line of sight
4. To square the boresight crossline

14-41. To prevent damage to threaded tubes in a boresight, you should manufacture special retainer ring wrenches.

494

Learning Objective: Recognize the principles of operation of night vision sights. Textbook pages 11-1 through 11-4.

14-42. A passive instrument is one that emits

1. no light but can be detected
2. no light and cannot be detected
3. light but cannot be detected
4. light and can be detected

14-43. How many times do passive instruments amplify available light?

1. 5,000 to 10,000
2. 20,000 to 30,000
3. 35,000 to 50,000
4. 50,000 to 75,000

14-44. Why is an infrared telescope considered an active instrument?

1. It generates a beam of infrared to illuminate targets
2. It can be detected by the enemy even without infrared-sensitive instruments
3. It cannot be detected by the enemy
4. It amplifies available light

14-45. A passive telescope consists of which of the following parts?

1. Image intensifier
2. Eyepiece system
3. Objective system
4. All of the above

14-46. How many stages does the image intensifier tube have?

1. One
2. Two
3. Three
4. Four

14-47. What weakness was present in the older type of IIT?

1. It did not amplify enough
2. It could not be used on all three NVS
3. It was too heavy for many uses
4. It would burn out from too much exposure

14-48. What is the closest distance on which the Mk 36 NVS can focus?

1. 1 yd
2. 2 yd
3. 3 yd
4. 4 yd

14-49. What is the focusing range of the Mk 37 NVS?

1. 30 yards to infinity
2. 40 yards to infinity
3. 50 yards to infinity
4. 60 yards to infinity

14-50. In the IIT, a.c. voltage is boosted to about how many volts?

1. 2,800 VAC
2. 11,500 VDC
3. 45,000 VAC
4. 45,000 VDC

14-51. What part of the metascope converts an invisible infrared light to a visible image?

1. Collective lens
2. Power amplifier
3. Eyepiece
4. Image tube in the receiver

14-52. To protect the repairman from electric shock when disassembling an NVS, the voltage in the IIT assembly must be discharged.

Learning Objective: Identify the parts and describe the systems and functions of various gunsight telescopes. Textbook pages 11-4 through 11-12.

14-53. What is the magnification of the Mk 67 gunsight?

1. Six
2. Five
3. Three
4. Four

14-54. A 5 inch-38 twin mount has how many Mk 67 gunsights?

1. Seven
2. Two
3. Three
4. Four

14-55. The line of sight in the Mk 67 gunsight is movable through how many degrees in elevation?

1. 15 degrees
2. 85 degrees
3. 90 degrees
4. 100 degrees

14-56. The reticle of the Mk 67 gunsight is located in the

1. first image plane
2. second image plane
3. image plane of the eyepiece
4. image plane of second erector

14-57. What is the allowable displacement of the horizontal line of a Mk 67 telescope at 90° elevation?

1. 1'
2. 2'
3. 30"
4. 90°

14-58. What part of the Mk 97 telescope is rotated to provide an interpupillary adjustment?

1. Reticle
2. Objective
3. Left rhomboid prism and eyepiece assembly
4. Compensator plate

14-59. The Mk 97 telescope is collimated to its mechanical axis.

14-60. What is the tolerance for the Mk 97 mirror parallelism?

1. 0.0075 inch
2. 0.075 inch
3. 0.00075 inch
4. 0.000075 inch

In items 14-61 through 14-64, select from column B the optical component that fits the telescope in column A.

	A. Telescope	B. Optical Component
14-61.	Mk 100	1. Skew penta prism
14-62	Mk 102 Mod 5	2. Auxiliary objective
14-63.	Mk 102 Mod 3	
14-64.	Mk 116	3. Porro prism

14-65. What is the magnification of the Mk 102 telescope?

1. 6X
2. 7X
3. 8X
4. 9X

14-66. How many prisms does the Mk 102 Mod 3 telescope have?

1. Five
2. Two
3. Three
4. Four

14-67. The entire Mk 116 or Mk 102 telescope is sealed and pressurized.

14-68. When an autocollimator is used on a Mk 116 telescope, which of the following conditions must exist before you can see the reflected image of the telescope crossline?

1. The test must be conducted in bright light
2. The elevation or traverse mechanism must be adjusted
3. Reticle illumination must be on
4. The servo chamber must be covered with a dark cloth

Assignment 15

Submarine Periscope

Textbook Assignment: Pages 12-1 through 12-21

Learning Objective: Expound the theory and identify the problems and solutions in the design of the submarine periscope. Textbook pages 12-1 through 12-4.

15-1. Which of the following features is/are necessary in a periscope if a submarine hopes to remain undetected while using the periscope?

1. Reflecting elements at the top and bottom
2. Sufficient length
3. A slender head section
4. Both 2 and 3 above

15-2. How is the periscope protected against the bending effect of motion through the water when the periscope is not in use?

1. By its rigid construction
2. By its large diameter tube
3. By lowering the scope
4. By using a flexible optical system

15-3. The possibility of internal fogging in a periscope is prevented by making the periscope completely waterproof.

15-4. How is a suitable field of view obtained in a periscope?

1. By using an upper telescope backwards in the system
2. By using a large head prism
3. By using a lower telescope backwards in the system
4. By reversing an upper and lower telescope in the system

15-5. If a periscope is designed with an upper telescope of 5X and a lower telescope of 25X, what is the overall power of the instrument?

1. 1/5X
2. 5X
3. 25X
4. 6X

15-6. What feature of periscope design allows use of a periscope underway without apparent target vibration?

1. A small diameter head section
2. Placing the telemeter in the lower auxiliary telescope
3. Placing the telemeter in the upper auxiliary telescope
4. Placing the telemeter above the auxiliary telescopes

15-7. The device for measuring ranges with a periscope is called a

1. telemeter
2. rangefinder
3. split lens
4. stadimeter

15-8. How much more power is available in a periscope in high power than in low power?

1. 1/4 as much
2. 1.5 times
3. 6 times
4. 4 times

15-9. When a periscope is charged with nitrogen, light will focus farther from the various lenses.

15-10. What factor of modern periscope design allows the manufacture of a scope of any reasonable length?

1. Optical relay components can be added or removed
2. A variable power upper telescope is used
3. The separation between erector lenses can be varied
4. A variable power lower telescope is used

15-11. What function does the 6th erector of a modern periscope serve?

1. It is the focusing element of the scope
2. It can be moved to bring the final image plane outside the scope
3. Both 1 and 2 above
4. It is one of the components of the scope ranging mechanism

---

Learning Objective: Identify periscopes. Textbook page 12-6.

15-12. The combination of numbers and letters, 123KA 43.3/HA, is used to describe a periscope's

1. serial number
2. design designation
3. registry number
4. design number

15-13. A type 8B periscope can be used to observe the area directly above a submarine.

15-14. A type 15B periscope can be found

1. second in line or on the port side
2. second in line or on the starboard side
3. first in line or on the port side
4. first in line or on the starboard side

Learning Objective: Recognize the correct methods of handling periscopes. Textbook pages 12-6 through 12-9.

15-15. The weight of a periscope is supported by

1. a hoisting yoke
2. a hydraulic yoke
3. the external fittings
4. the periscope well bumper

15-16. In a periscope hoisting yoke, the scope and yoke are connected by the

1. cover ring
2. hoist rods
3. split rings
4. hoist yoke

15-17. When a submarine is underway submerged, how can the drag of a raised periscope be reduced?

1. Streamline the periscope
2. Streamline the sail
3. Lower the periscope
4. Raise the fairing

15-18. A dependent fairing will not cause any problems when a periscope is removed from a submarine.

15-19. When a periscope must be removed from a submarine, the job can proceed without further contact with submarine personnel.

15-20. How many optical shop personnel are usually involved in preparing a periscope for removal?

1. One
2. Six
3. Three
4. Four

Learning Objective: Identify the sequence of events required to remove a periscope. Textbook pages 12-9 through 12-11.

15-21. You have boarded a submarine to raise a periscope. After notifying the submarine duty officer, what should you do first?

1. Inform your division officer
2. Have enough personnel to do the job
3. Attach a safety harness to the scope
4. Make sure the sail is clear

15-22. When a periscope is being clamped, where should the clamps be located?

1. At least 18 inches from the outer tapered tube
2. No more than 18 inches below the outer tapered tube
3. At least 18 inches from the observing position
4. No more than 18 inches above the outer tapered tube

15-23. In what order should clamps be attached to a periscope?

1. Two safety clamps first, then the hoisting clamp
2. Hoisting clamp first, then two safety clamps
3. Safety clamp, hoisting clamp, safety clamp
4. Hoisting clamp, safety clamp, hoisting clamp

15-24. Even though periscope handling equipment is regularly tested and inspected, you should NOT use any gear until you are satisfied that it is in good working order.

15-25. When, if ever, should a clamped periscope be protected with a wrapping of plastic?

1. Every time a scope is pulled
2. When emery cloth is used between the scope and clamps
3. When the scope must remain clamped while you work on associated equipment
4. Never

15-26. What must you do before clamping and elevating a general purpose periscope?

1. Remove external fittings
2. Disconnect the E&E adapter
3. Remove the stub antenna
4. Both 2 and 3 above

15-27. How, if at all, do you match external fittings with any particular periscope?

1. The serial number is stamped on the fittings
2. The registry number is stamped on the eyepiece
3. Punch marks are aligned between scope and fittings
4. Matching is not necessary; external fittings are interchangeable

15-28. A periscope stadimeter is held to the eyebox with

1. a lockring
2. an electrical connection
3. spring-loaded plungers
4. four captive bolts

15-29. After removing the hoist yoke from a scope, how should you remove the upper bearing race?

1. Lift it out of the hoist yoke
2. Pry the split rings out and remove the race
3. Tap the race off the split rings
4. Remove the setscrews and remove the race

15-30. When all preparations for pulling a scope have been completed, the periscope should be pulled regardless of the trim of the submarine.

Learning Objective: Indicate the elements of coordination, training, and proper auxiliary equipment in periscope handling. Textbook pages 12-11 and 12-12.

15-31. What purpose does a hinge carriage serve?

1. It counterbalances the scope
2. It protects the scope split ring groove
3. It protects the outer tube of the periscope
4. It allows the scope to be safely lowered to a horizontal position

15-32. If the outer tube of a scope is 32 feet long, where should V-blocks be located when a scope is in a horizontal position?

1. 8 feet from each end
2. 10 feet apart
3. 12 feet from the center
4. 4 feet from each end

15-33. A strong back is used on a periscope before the clamps or hinge carriage is removed.

15-34. When a periscope in a shipping container is to be transported by truck which of the following should be done?

1. The eyebox end should be to the rear of the truck
2. A truck longer than the shipping container should be used
3. The taper section should be to the rear of the truck
4. External fittings should be packaged separately

Learning Objective: Indicate the approved method of packing a periscope. Textbook pages 12-12 and 12-13.

15-35. Even though the area of a submarine hull around a scope must be tightly sealed against entry of seawater, the scope is still free to turn.

15-36. What factors affect the seal between the periscope and hull casting of a submarine?

1. Concentricity of packing assembly components
2. Well formed chevron packing
3. Both 1 and 2 above
4. Seawater pressure on the periscope outer tube

15-37. What is the purpose of a slight clearance between the lower steady bearing and upper packing ring of a periscope packing assembly?

1. To compensate for swelling of the chevron packing
2. To provide a space for lubrication
3. To allow water pressure to compress the packing
4. To align the packing with the hull casting

15-38. Any inaccuracy of the metal components in a packing assembly can be disregarded since the chevron packing will compensate for such errors.

15-39. When should the packing assembly be removed from a submarine?

1. As the scope is being pulled
2. Before the scope is pulled
3. After the scope is installed
4. After the scope is removed

15-40. Periscope packing can be removed without pulling the scope.

Learning Objective: Recognize the steps in installing and repacking periscopes. Textbook pages 12-13 through 12-15.

15-41. Which of the following conditions is the most important consideration in replacing a periscope?

1. Time of day
2. Time to complete the job
3. Proper scheduling
4. Other work in the shop

15-42. If a periscope is being replaced with a longer one, the new scope should be clamped

1. lower than the original scope
2. higher than the original scope
3. in the same location as the original scope
4. 18 inches from the outer taper section

15-43. As a periscope is being lowered into a submarine, the person on the sail performs which of the following functions?

1. Forces the periscope into alignment with the hole in the sail
2. Coats the periscope with grease
3. Secures the periscope with a safety harness
4. Unhooks the periscope from the slings

15-44. What is the maximum amount of clearance allowed between the lower steady bearing and top packing ring?

1. 1/16 inch
2. 1/32 inch
3. 3/16 inch
4. 3/32 inch

15-45. Why are packing sticks necessary in repacking the periscope?

1. For greasing the packing assembly
2. For inserting packing assembly components into the hull casting
3. For measuring the clearance between the assembled packing and lower steady bearing
4. For raising the yoke cover ring into position

500

15-46. When you are installing various rings of chevron packing, you should take some precautions to avoid damaging the packing.

15-47. What is the required clearance between the periscope and installed packing assembly?

1. 1/16 inch
2. 1/32 inch
3. 0.006 inch
4. 0.012 inch

15-48. Once a packing job has been completed and the scope has been cycled up and down several times, no further testing of the packing is necessary.

15-49. When the periscope yoke is being raised into position, you should guide it over the eyebox to

1. align it with the upper race
2. align it with the yoke cover
3. avoid catching a hoist rod
4. prevent catching the eyebox

Learning Objective: Identify the features of maintaining periscope external fittings. Textbook pages 12-15 through 12-21.

15-50. What components hold the eyeguard adapter on a periscope faceplate?

1. Detent plungers
2. Lockrings
3. Three screws
4. Tension springs

15-51. What is the required spacing between the eyelens elements of a periscope eyepiece?

1. 0.001 inch
2. 0.002 inch
3. 0.037 inch
4. 0.400 inch

15-52. What should you do to threaded sections of an eyepiece assembly as it is being reassembled?

1. Use a thread locking compound
2. Lubricate the threads lightly
3. Secure the part, then back it out 1/8 turn
4. Secure the part, then back it out 1/4 turn

15-53. What components of a blinder attachment would you normally expect to repair?

1. Eyeguard adapter studs
2. Broken finger lever springs
3. Deteriorated eyeguards
4. Both 2 and 3 above

15-54. Both filter elements of the variable density filter assembly are free to rotate.

15-55. What component of the variable density filter attachment causes the cradle to rotate?

1. The face ring
2. A screw attached to the cradle
3. The actuator sleeve
4. Both 2 and 3 above

15-56. How is the eyeguard mount secured in the face ring of a variable density filter attachment?

1. Friction screw tension
2. Thread sealing compound
3. Spring tension
4. Spring detents

15-57. When the variable density filter attachment is properly assembled, the index marks of the filters should be in which of the following positions, and why?

1. Aligned vertically to provide minimum light transmission
2. Aligned horizontally to provide minimum light transmission
3. Aligned vertically to reduce glare with maximum light transmission
4. At 90° to each other to reduce glare with maximum light transmission

15-58. To provide maximum light transmission through a variable density filter assembly, the actuator sleeve is turned counterclockwise.

15-59. What is the most important precaution to observe when you overhaul a pressure gage and valve assembly?

1. Replace the gage during each periscope overhaul
2. Avoid damaging O-ring seating surfaces
3. Avoid damaging O-rings
4. Replace only worn O-rings

15-60. A periscope focusing knob provides a focus range of +1.5 to 10 diopters.

15-61. Before a scope focusing knob can crank the 6th erector into camera position, what must you do?

1. Turn the knob to the stop, clockwise
2. Extend the spring-loaded handle
3. Pull out the detent plunger
4. All of the above

15-62. What holds the focusing knob on the focusing shaft?

1. A retainer ring
2. A retaining nut
3. Friction
4. Both 2 and 3 above

15-63. What components of the focusing knob assembly rotate when the knob is turned?

1. Focusing shaft, camera stop, focusing stop
2. Focusing nut, focus knob, focus stop
3. Camera stop, focusing nut, focusing stop
4. Diopter ring, focus knob, focusing nut

15-64. Replacement parts for the focusing knob assembly are interchangeable and no adjustment is necessary.

15-65. The end of the focusing shaft is slotted to allow

1. focusing without using the focus knob
2. tightening the focus shaft and knob
3. removal of the focus shaft
4. adjustment of the stops while the focus knob assembly is on the scope

Assignment 16

Submarine Periscopes (Continued)

Textbook Assignment: Pages 12-21 through 12-50

Learning Objective: Recognize the steps in assembling the left and right training handle assemblies of periscopes. Textbook pages 12-21 through 12-23.

16-1. If the bevel gears or stops on the left training handle of a scope have been renewed, the handle operation should NOT be checked until the handle is replaced on the scope.

16-2. Incorrect adjustment of the right training handle of a type 2 periscope can cause which of the following problems?

1. Incorrect elevation and depression
2. Stretched shifting tapes
3. Insufficient lens cube travel
4. Both 2 and 3 above

16-3. Which of the following periscopes use a sextant mark switch in the right training handle?

1. Type 2, type 8, type 15
2. Type 2 and type 8
3. Type 15 and type 8
4. Type 15 and type 2

16-4. In addition to actuating a motor to assist with training a periscope, how many other functions are incorporated in a type 15 scope right training handle?

1. Five
2. Two
3. Three
4. Four

16-5. In a type 15 right handle, what device is needed to check the correct electrical function?

1. Micrometer
2. Wiring harness
3. Multimeter
4. Electrical troubleshooter

16-6. What feature of the stadimeter dial and drive assembly allows the repairman to obtain full travel of the split lens?

1. Special couplings between the stadimeter and scope
2. An adjustable stop on the stadimeter drive shaft
3. An adjustable stop on the stadimeter in-out lever
4. Special couplings on the stadimeter drive shaft

Learning Objective: Identify the procedures in periscope maintenance and repair. Textbook pages 12-25 through 12-37.

16-7. What is the first step in repairing a periscope?

1. Disassemble externals
2. Perform a casualty check analysis
3. Release gas pressure
4. Roll the scope and listen for loose screws

16-8. What is the prime requirement of the optical shop once the scope is opened?

1. The shop must be scrupulously clean
2. The shop must be dust free
3. The shop must be air conditioned
4. The shop must be pressurized

16-9. Before removing the inner tube of a periscope from the outer tube, what should you do first?

1. Release gas pressure
2. Disconnect all antennas
3. Set the head prism at zero elevation
4. Roll the scope so the head window is facing up

16-10. What assures alignment of the inner tube and outer tube?

1. One setscrew
2. Two setscrews
3. A key
4. A coupling

16-11. In removing the inner tube from the outer tube, attach a chain hoist to the eyebox when

1. you start the coupling action
2. the main coupling has been unscrewed
3. the key is in view
4. the eyebox is free of the outer tube

16-12. When the inner tube has been removed and placed on the rail, it is supported by

1. straps
2. wedges
3. V-blocks
4. bolts

16-13. What is done to keep dirt out of the outer tube?

1. Stand it on end
2. Put rags in the ends
3. Tape ends with masking tape
4. Plug ends with DC plugs

16-14. In disassembling a type 15 inner tube, you must first remove the

1. waveguide
2. shafting
3. head prism
4. eyebox

16-15. Shafts in a periscope are connected by which of the following means?

1. Universal joints
2. Keyed joints
3. Taper pins
4. All of the above

16-16. Each time the inner tube is disassembled, the tube sections must be renumbered.

16-17. Which of the following is one difference between a type 2 and a type 15 eyebox?

1. Type 2 has a synchro mechanism
2. Type 2 has an antenna waveguide and cables
3. Type 15 has two more control shafts
4. Type 2 has two more control shafts

16-18. Because of the simple construction of the focusing erector assembly, you should disassemble it for easy access to clean the lens.

16-19. The focusing assembly has how many stops?

1. One
2. Two
3. Three
4. Four

16-20. Where is the upper stop in the focusing assembly positioned during preliminary assembly?

1. One thread lead from top
2. Two thread leads from top
3. 1 inch from the top
4. 2 inches from the top

16-21. After the focusing assembly has been assembled, the unit should then be

1. drilled and tapped
2. drilled and dowel pinned
3. sealed with masking tape
4. tested for binding

16-22. What element(s) of the skeleton head is/are easily replaced?

1. Head prism
2. Galilean eyelenses
3. Galilean objectives
4. All of the above

16-23. What means is provided to remove parallax in low power?

1. Setscrews
2. A threaded lens cell
3. Elongated screw holes
4. Eccentric screw holes

16-24. What keeps the cubes in the desired position?

1. Position stops
2. Tight bearings
3. Detent springs
4. Detent retainers

16-25. The elevation stops in the skeleton head are positioned to provide

1. 1/4° overtravel
2. 85° total travel
3. 1° overtravel
4. an exact elevation angle

16-26. Why are the skeleton heads of type 8 and 15 periscopes optically and electrically aligned?

1. So the scopes can be used for attack
2. So the scopes can be used for navigating
3. To determine the amount of error in elevation
4. Both 2 and 3 above

16-27. What is the allowable displacement in shifting from the split lens to the solid erector?

1. 0.0003 inch
2. 5 mm of focal length
3. ±5 min. of arc
4. 0°

16-28. If the solid erector is replaced, how can it be parfocalized with the split lens?

1. By increasing or decreasing spacer thickness of the solid lens
2. By increasing or decreasing spacer thickness of the stadimeter lens
3. By positioning the solid lens
4. By replacing both lenses

16-29. The inner tubes are rapped with a soft hammer to remove dirt.

16-30. What lens is used to check the cleanliness of an assembled periscope?

1. Eyelens
2. 3rd erector
3. 5th erector
4. 6th erector

16-31. On the type 15 periscope, the telemeter is located between the field flattener and the

1. first erector
2. sealing window
3. Galilean objective
4. objective

16-32. What keeps the telemeter clean when the scope is gassed?

1. Shop environment
2. Cheese cloth
3. An air filter
4. Nitrogen

Learning Objective: Indicate the steps in collimating subassemblies of periscopes. Textbook pages 12-37 through 12-44.

16-33. In collimating a periscope, you must also compensate for the charging gas.

16-34. In collimating the scope, what must you focus first?

1. The objective on the telemeter
2. The objective on the collimator
3. The first erector on the collimator
4. The first erector on the telemeter

16-35. What is the purpose for adjusting the high power objective?

1. To focus on the collimator reticle
2. To focus on the telemeter
3. To remove parallax between the collimator reticle and telemeter lens
4. To remove parallax between the objective and telemeter lens

16-36. What is the allowable focal length variation between the first pair of erectors?

1. 1%
2. 2%
3. 3%
4. 4%

16-37. When collimating the second, third, and fourth erectors of a type 15 scope, at what setting should you set the collimator?

1. 3,171 ft
2. 49 ft
3. 52 ft
4. Infinity

16-38. When parallax has been removed from the focusing erector, the setting will be 0 diopters when the scope is charged.

16-39 Which of the following steps is required to align the split lens with the eyebox?

1. Square the transit to the eyebox
2. Square the eyebox to the transit
3. Rotate the scope to align the split lens to the transit
4. All of the above

16-40. After all the erectors have been collimated, which of the following components should be installed?

1. Skeleton head
2. Inner tubes
3. Power shifting tapes
4. All of the above

16-41. When squaring the telemeter of a type 2 periscope, what should you use as a reference?

1. Telemeter
2. Collimator
3. Square
4. Transit

16-42. If the collimator appears to move to either side of vertical as the head prism is being elevated or depressed, what should you rotate to correct the displacement?

1. Telemeter
2. Skeleton head
3. Head prism
4. Split lens

16-43. Before squaring the head prism of a type 8 or 15 scope to the telemeter, you must do which of the following?

1. Position the split lens
2. Square the staunching plate to the transit
3. Square the eyebox to the skeleton head
4. Square the split lens to the eyebox

16-44. What must you do before you can check the elevation and depression of the line of sight?

1. Elevate the scope
2. Rotate the scope
3. Adjust the center of rotation of the collimator to align with the rotation of the head prism
4. Depress the scope

16-45. The head prism must travel through how many degrees on a type 15 scope?

1. 45°
2. 60°
3. 70°
4. 90°

16-46. How much parallax is allowed when you shift from high to low power?

1. 0 diopter
2. 1/4 diopter
3. 2 diopters
4. 3 diopters

16-47. Why is it necessary to remove the horizontal and vertical displacement when you shift power?

1. To keep the crossline square
2. To prevent the need to retrain the scope
3. To keep the image from jumping
4. To keep the reticle from jumping

16-48. Which scope has just a vertical reference telemeter?

1. Type 2
2. Type 3
3. Type 8
4. Type 15

16-49. What is the preferred amount of displacement of the vertical and horizontal crosslines when you shift power?

1. 2' horizontal 10' vertical
2. 10' horizontal 2' vertical
3. 2' horizontal 2' vertical
4. 0' horizontal 0' vertical

16-50. On the type 2 scope, displacement between the split lens and fifth erector is removed by adjusting the

1. split lens stop
2. cube detent
3. focusing erector
4. stops in the stadimeter

16-51. When using the preferred method of making a range check with the stadimeter, which of the following procedures should you follow?

1. Set the height scale at 20 ft
2. Set the scope in high power
3. Use successive marks on the collimator
4. All of the above

16-52. Accuracy of the stadimeter in the ranging tests must be within

1. ±1%
2. ±2%
3. ±3%
4. ±5%

Learning Objective: Recognize the elements of periscope final assembly and cycling. Textbook pages 12-44 through 12-50.

16-53. In the final assembly of the scope, which of the following steps must you take prior to inserting the inner tube into the outer tube?

1. Attach the wiring harness
2. Make a final check of all joints
3. Rotate the scope so that the head prism is facing up
4. All of the above

16-54. The distance between the eyebox and the coupling and between the outer tube and the coupling should be within

1. one thread
2. two threads
3. 1/16 inch
4. 1/8 inch

16-55. What is the sequence of cycling a periscope?

1. Pressurize, vacuumize, and charge
2. Vacuumize, pressurize, and charge
3. Charge, pressurize, and vacuumize
4. Pressurize, charge, and vacuumize

16-56. When a periscope is being charged, the flow rate should be

1. 3 to 5 psi every 5 min
2. 50 psi
3. 5 psi every 4 min
4. 3 to 5 cubic feet per min

16-57. As the periscope is being charged, you should make several soap solution checks for leaks.

16-58. How long should it take to release the internal pressure after pressure testing a periscope?

1. 30 min
2. 45 min
3. 60 min
4. 90 min

16-59. After pressure testing, moisture is removed from the periscope by what process?

1. Packing with silica gel
2. Freezing with dry ice
3. Pulling a vacuum on it
4. All of the above

16-60. If electrical power to the vacuum pump is lost while drawing a vacuum, its oil will be sucked into the periscope.

16-61. The periscope should hold how much vacuum for how long?

1. 3 mm for 4 hrs
2. 2 mm for 3 hrs
3. 3 mm for 3 hrs
4. 4 mm for 3 hrs

16-62. What safety precautions must you observe when handling the dry ice and acetone mixture?

1. Wear gloves
2. Wear eye protection
3. Protect the skin against frostbite
4. All of the above

16-63. The dewpoint of a periscope should be

1. -50°F
2. -55°F
3. -55°C
4. -60°C

16-64. How often should periscopes be cycled?

1. Every 6 months
2. When fogging is noticed
3. Both 1 and 2 above
4. During each upkeep

✩ U.S. GOVERNMENT PRINTING OFFICE: 1980-640-266/90

COURSE DISENROLLMENT

All study materials must be returned. On disenrolling, fill out only the upper part of this page and attach it to the inside front cover of the textbook for this course. Mail your study materials to the Naval Education and Training Program Development Center.

PRINT CLEARLY

NAVEDTRA Number	COURSE TITLE
10205-B	OPTICALMAN 3&2

Name Last First Middle

Rank/Rate Designator Social Security Number

COURSE COMPLETION

Letters of satisfactory completion are issued only to personnel whose courses are administered by the Naval Education and Training Program Development Center. On completing the course, fill out the lower part of this page and enclose it with your last set of self-scored answer sheets. Be sure mailing addresses are complete. Mail to the Naval Education and Training Program Development Center.

NAVEDTRA 10205-B OPTICALMAN 3&2

NAME

ZIP CODE

MY SERVICE RECORD IS HELD BY:

Activity

Address ZIP CODE

Signature of enrollee

PDD Form 111

A FINAL QUESTION: What did you think of this course? Of the text material used with the course? Comments and recommendations received from enrollees have been a major source of course improvement. You and your command are urged to submit your constructive criticisms and your recommendations. This tear-out form letter is provided for your convenience. Typewrite if possible, but legible handwriting is acceptable.

Date____________________

From: ____________________________________

____

____________________________________ ZIP CODE_________

To: Naval Education and Training Program Development Center (PD4)
Building 2435
Pensacola, Florida 32509

Subj: NRCC Opticalman 3&2, NAVEDTRA 10205-B

1. The following comments are hereby submitted:

(Fold along dotted line and staple or tape)

(Fold along dotted line and staple or tape)

DEPARTMENT OF THE NAVY
NAVAL EDUCATION AND TRAINING PROGRAM
DEVELOPMENT CENTER (PD 4)
PENSACOLA, FLORIDA 32509

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
NAVY DEPARTMENT
DoD-316

U.S.MAIL

NAVAL EDUCATION AND TRAINING PROGRAM DEVELOPMENT CENTER
BUILDING 2435 (PD 4)
PENSACOLA, FLORIDA 32509

510